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Summary Report

Fine Pore (Fine Bubble) Aeration Systems

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Contents

Introduction and Overview

Aerobic biological processes continue to be one of the more popular methods employed to treat municipal and industrial wastewaters. The supply of oxygen to the biomass in activated sludge systems and aerated lagoons represents the single largest energy consumer in wastewater treatment facilities. Recent studies indicate that from 50 to 90 percent of the net power demand for a treatment plant lies within the aeration system.[1] A general survey of data made available in 1982 on municipal and industrial wastewater treatment installations suggests that on the North American Continent there are approximately 1.3 million kw (1.75 million hp) of aeration equipment in place at an installed value of 0.6 to 0.8 billion dollars.[2] Operating costs for these systems may be expected to be about 0.6 billion dollars/yr.

Originally, oxygen was diffused into wastewater through perforated pipes located at the bottom of the aeration tank. The development of the porous plate was considered an important advance in the diffused aeration process because of the higher oxygen transfer efficiency offered by this fine pore device.[3] Porous diffuser plates were used as early as 1916 and became the most popular method of aeration in the 1930s and 1940s.[4,5] It was clear shortly after the development of porous diffusers that clogging could be a problem. Early work on clogging led to the use of coarser media[6] and eventually to large orifice devices.[7] The use of mechanical aeration devices was another answer to the clogging problem, although these devices were normally applied to small treatment facilities and industrial waste applications.[7]

The energy crisis of the early 1970s rekindled interest and awareness within the sanitary engineering community relative to the efficiency of oxygen transfer systems. As a result, the fine pore diffusion of air has gained renewed popularity as a very competitive system. Yet, considerable concern has been registered regarding the performance and maintenance of fine pore diffusion systems owing to their susceptibility to clogging. Diffuser clogging, if severe, may lead to deterioration of aeration efficiency and corresponding escalation of power costs. Furthermore, troublesome maintenance of diffusers may consume considerable amounts of operator time and plant operating budget.

The purpose of this summary report is to provide current information on the performance, operation and maintenance, and retrofitting of fine pore aeration systems in municipal wastewater treatment service. It is not intended to be a design manual, but rather to provide a general conceptual framework for practicing engineers to assist them in the selection, specification, design, and control of fine pore aeration systems.

"Fine bubble" diffused aeration is elusive and difficult to define. The term "fine pore" is used hereafter instead of "fine bubble" to more nearly reflect the porous characteristics of the diffusers themselves. Typically, fine pore diffusers will produce a headloss due to surface tension in clean water of greater than about 5 cm (2 in.) water gauge. For the purposes of this report, fine pore diffusers are defined as including the following diffusion devices:

- Porous ceramic plates, discs, domes, and tubes
- Porous plastic plates, discs, and tubes
- Flexible sheath tubes

This summary report is divided into five major sections: Description of Devices; Performance Characteristics; Operation and Maintenance Considerations; Retrofit Considerations; and Ongoing Activities. It will be followed in approximately 2 years with a comprehensive design information manual on fine pore diffused aeration based on studies being conducted here and abroad to fill gaps in the current state-of-the-art.

Description of Devices

Since the introduction of the activated sludge process in the early 1900s, a number of different types of diffused aeration devices have been designed and developed to introduce air into liquids. These have ranged from individual orifices (holes or slots) drilled in a section of pipe to more elaborate devices made up of small diameter particles fused together. Today, although the same types of generic devices exist, diffusers are commonly classified as either fine or coarse bubble.

The demarcation between fine and coarse bubbles is not well differentiated. Coarse bubble diffusers will typically produce a bubble diameter of 10 to 20 mm in clean water. So-called fine bubble (fine pore) diffusers, when new, will produce bubbles with a diameter of 2 to 4 mm in clean water.[8–10] Some references also describe a medium bubble diffuser,[11] which can be assumed to produce a bubble diameter somewhere in between.

Types of Fine Pore Diffusion Media

A number of porous materials capable of serving as effective aeration devices are marketed today. In general, a wide range of products that were initially developed to filter air have also been found to act as satisfactory air diffusion devices. Because of cost and specific characteristics, only a few of these materials are actually being used in the wastewater treatment field.

Ceramic Materials

The oldest and still the most common type of porous material on the market is the ceramic type. It consists of rounded or irregular-shaped mineral particles bonded together to produce a network of interconnecting passageways through which compressed air flows. As the air emerges from the surface pores, pore size, surface tension, and air flow rate interact to produce a characteristic bubble size.[12]

Ceramic diffusers manufactured from glass- or resin-bonded silica or alumina are available. The two most popular materials are glass-fused silica and glass-fused alumina.

The silica material is produced from naturally occurring sand particles. After screening to obtain the desired uniform particle size, an amorphous glass binder is added. The aggregate and binder mix is then pressed in a mold to produce the desired shape. After pressing, the material is fired at approximately 980°C (1800°F). At this temperature, the binder material encapsulates the sand particles. When the mix is cooled, a glass bond is formed by the binder material at the contact points between the individual particles.

The alumina material is made from aluminum oxide. The actual grains are produced by melting bauxite ore at approximately 2050°C (3720°F) to form large pigs. The pigs are then crushed and the resulting particles screened to select the desired size. For the alumina, an elaborate binder resembling porcelain is used. After pressing, the grit and binder mix is fired at 1425°C (2600°F), which upon cooling creates the glass bond at the contact points. The final product is typically 80 to 90 percent aluminum oxide.

A few minor differences exist between the two types of material. Because of the crushing process, the alumina grains are more angular and jagged in shape than the silica particles. Silica is a mined material with a limited particle size range, and the pore size that can be produced with it is limited by naturally occurring grain sizes.

In general, for wastewater treatment applications, the performance of both silica and alumina is expected to be approximately the same. It has been claimed that the silica material, because of its shape, may be more resistant to fouling and more easily cleaned.[10] This claim has not been well demonstrated based on controlled experiments.

Today, the majority of ceramic diffusers being marketed are manufactured from aluminum oxide. The alumina material is harder and possibly somewhat stronger than silica, but this probably is not the sole reason for its widespread use. Just as important may be the fact that essentially all ceramic media are manufactured by large companies whose major product line is abrasive materials (aluminum oxide grinding wheels). Because the air diffusion market is relatively small in comparison, it is difficult to justify the use of different raw materials for the manufacture of air diffusion equipment.

Plastic Materials

A more recent development in the fine pore diffuser field is the use of porous plastic materials. As with the ceramics, a material is created consisting of a number of interconnecting channels or pores through which compressed air can pass. Advantages of the plastic material over aluminum oxide are its lighter weight (which makes it especially well suited to lift-out applications), lower cost, better durability, and, depending on the actual material, greater resistance to breakage. Disadvantages include its reduced strength and susceptibility to creep.

Porous plastics are made from a number of thermoplastic polymers including polyethylene, polypropylene, polyvinylidene fluoride, ethylene-vinyl acetate, styrene-acrylonitrile, and polytetrafluoroethylene.[13] Probably the two most common types of plastic materials in use are high density polyethylene (PE) and styrene-acrylonitrile (SAN). PE is used because it is relatively easy to process when compared with other thermoplastics. Shrinkage is low, a uniform quality product can be obtained, and small pore sizes can be produced. The actual material is manufactured by a proprietary process, and, thus, little information is available on it. One manufacturer[14] did indicate that the PE media contains no binders or additives, is non-polar, and is made from a straight homo-polymer (not a blend).

A European manufacturer produces a double-layer PE material.[15] It consists of a grainy, open-pore structure covered with a thin film layer. The manufacturer claims that the double layer results in a filtering effect that decreases the required maintenance. Presumably the lower maintenance would result from a reduction in air-side fouling of the diffuser. If the air supply is properly filtered, air-side fouling will likely not be a problem so the savings in maintenance costs would be minimal. The thin outer layer is, however, potentially beneficial in helping to produce a small diameter bubble uniformly over the diffuser surface. The corresponding increased tendency for external fouling to occur, if any, is unknown.

The major advantages of the PE media compared with the other plastic alternatives are that it is lighter in weight (approximately 560 kg/m^3 (35 lb/cu ft)), essentially inert, and will not break, even under freezing conditions. In addition to the disadvantages previously mentioned, the PE material is also a relatively new product (at least as an air diffusion device) and all of the long-term effects may not be known.

The second most common type of thermoplastic material is SAN copolymer. The raw material is a mixture of four different molecules. Physically, the media is made up of very small resin spheres that are fused together under pressure. The SAN media has a density only slightly greater than PE. The presence of the styrene, however, makes the material brittle, and the media can break if dropped, even at room temperature. A major advantage of the SAN material is that is has been in use for approximately 15 years without known deleterious effects.

Flexible Sheaths

Flexible diffusers have been in use for approximately 40 years. They initially were referred to as "sock" diffusers and were made from materials such as plastic, synthetic fabric cord, or woven cloth. Because of the woven type sheaths, a metallic or plastic core material was necessary for structural support. Although sock diffusers were capable of achieving relatively high oxygen transfer rates, fouling problems were often severe. Today, there is essentially no market for the early sock design.

Within the last several years, a new type of flexible diffuser has been introduced. It consists of a thin flexible sheath made from soft plastic or rubber. Air passages are created by punching minute slots in the sheath material. When the air is turned on, the sheath expands. Each slot acts as a variable aperture opening; the higher the air flow rate the greater the opening. The sheath material is supported by a tubular frame.

This new generation of flexible diffusers has been in operation at a number of facilities for the last several years. The new sheath material has reduced the severe fouling problems associated with the earlier woven fabric design. The manufacturer estimates sheath life to be about 5 years.[16]

Types of Fine Pore Diffusers

Today, there are four general shapes of fine pore diffusers on the market: plates, tubes, domes, and discs. Each will be discussed in detail in the subsections that follow.

Plate Diffusers

The original fine pore diffuser design was a flat rectangular plate. Plates are typically 30 cm (12 in.) square and 2.5 to 3.8 cm (1 to 1.5 in.) thick. They are manufactured from either glass-bonded silica or glass-bonded aluminum oxide. The plates are installed in the tank by grouting them into recesses in the floor, cementing them into prefabricated holders, or clamping them into metal holders. Of the three, the metal holders are the least attractive because corrosion of the holders tends to foul the underside of the diffusers. A chamber underneath the plates acts as an air plenum. The number of plates fixed over a common plenum is not standard and can vary from only a few to 500 or more. In current U.S. designs, individual control orifices are not provided on each plate.

Fine pore plates were used almost exclusively as the method of air diffusion in the early activated sludge plants through the 1920s. Today, other than in some of the original plants, fine pore plates are not often specified and installed. Some possible explanations for their decline in popularity include 1) problems obtaining uniform air distribution with a number of plates attached to the same plenum, 2) the inconvenience of removing plates when they are grouted in place, and 3) the difficulty in adding diffusers to meet future increases in plant loading.

Tube Diffusers

Like the plates, fine pore tubes have been used in wastewater treatment for a number of years. The early tubes, Saran wound or made from aluminum oxide, have been followed by the introduction of SAN copolymer, porous PE, and, most recently, the new generation of flexible media.

All the tube diffusers on the market are of the same general shape. Typically, the media portion is 50 to 60 cm (20 to 24 in.) long and has an O.D. of 6.4 to 7.6 cm (2.5 to 3.0 in.). The thickness of the media is variable. Flexible sheaths are very thin, commonly in the range of 0.5 to 1.3 mm (0.02 to 0.05 in.). The PE media is usually supplied with a thickness of 6.4 mm (¼ in.), the SAN media at approximately 15.2 mm (0.6 in.), and fused ceramic material in the range of 9.5 to 12.7 mm (⅜ to ½ in.).

The holder designs for the ceramic and porous plastic media are very similar. Most consist of two end caps held together by a connecting rod through the center. The rod is threaded into the feed end of the holder, the media and outer end cap installed, and a hex nut placed on the threaded rod to secure the assembly. In another version, the feed end cap and inner support are one piece with the assembly held together by a bolt installed through the outer end cap and threaded into the support frame. For both designs, gaskets are placed between the media and the end caps to provide an air-tight seal. In some cases, a gasket or O-ring is also used in conjunction with the retaining bolt or hex nut. Typical porous plastic tube diffuser assemblies are shown in Figure 1.

For the flexible sheath diffusers, the end caps and support frame are one piece. The sheath is installed over the support frame and clamped on both ends. In this design, no gaskets are required. A typical flexible sheath diffuser assembly is illustrated in Figure 2.

To prevent corrosion, all components of the various tube assemblies are either stainless steel or durable plastic. The gaskets are usually of a soft rubber material.

Tube diffusers are designed to operate in the air flow range of 1 to 5 L/s (2 to 10 scfm). Because of their inherent shape, it is sometimes difficult to obtain air discharge around the entire circumference of the tube. The air distribution pattern will vary with different types of diffusers. In general, however, the extent of inoperative area will be a function of the air flow rate and the headloss across the media. Because dead areas can provide sites for slime growth and other foulant

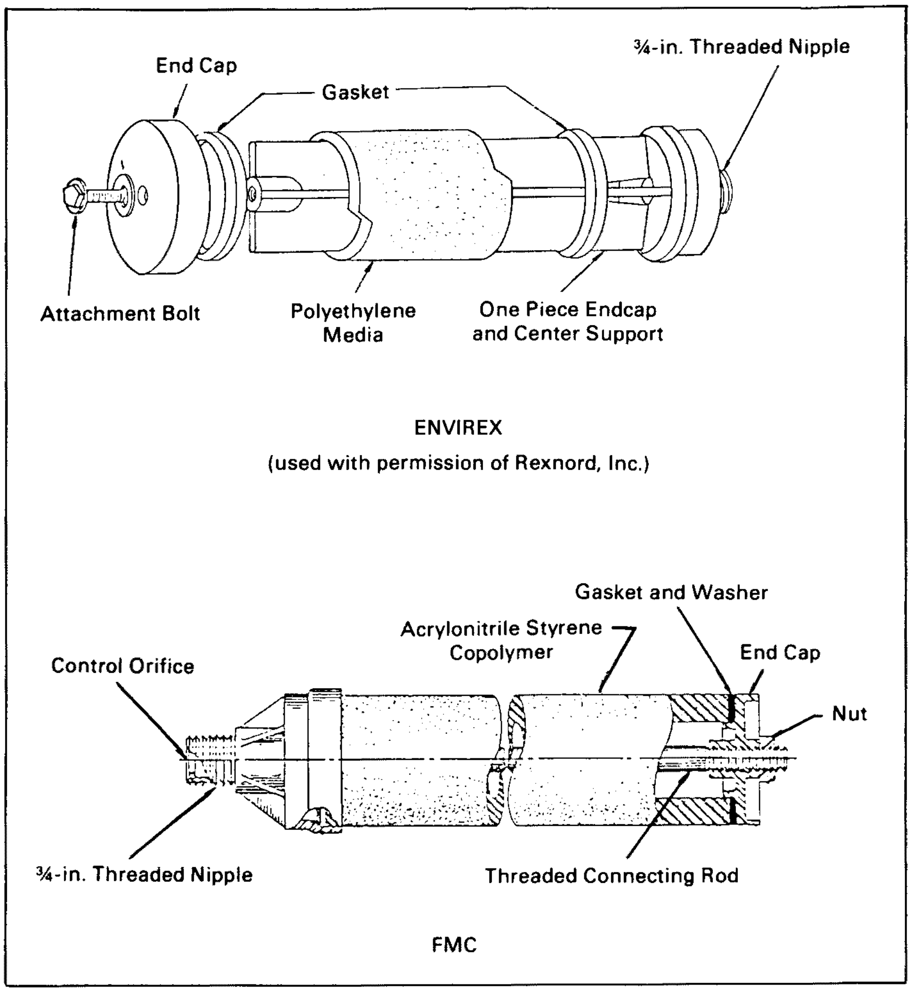


Figure 1.

Typical Porous Plastic Tube Diffusers

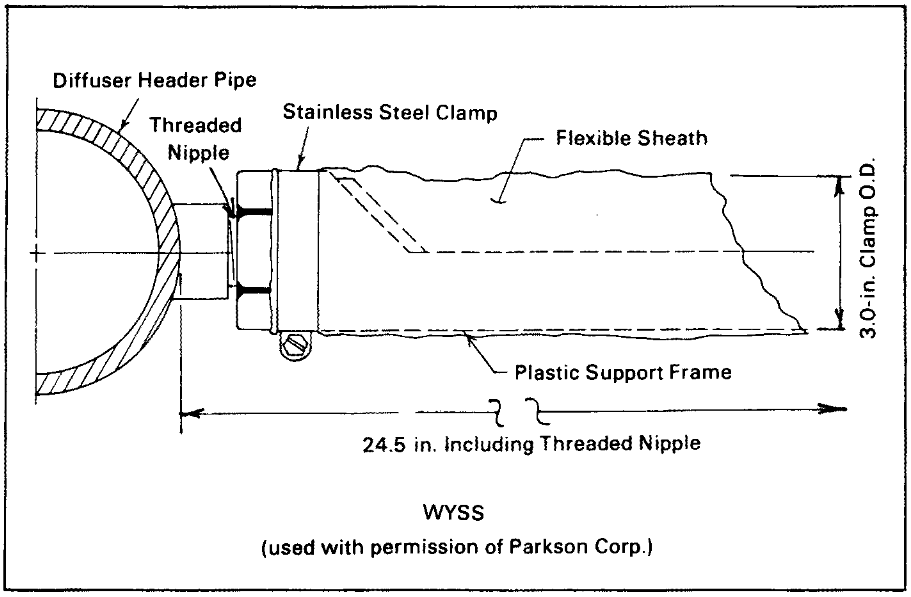


Figure 2.

Typical Flexible Sheath Tube Diffuser

development, it would be beneficial prior to selecting a particular tube design to observe its performance on a laboratory- or pilot-scale basis.

Most tube assemblies are fitted with a control orifice inserted in the inlet nipple to aid in air distribution. Typically, the orifice is approximately 13 mm (0.5 in.) in diameter, although different sizes can be used for various design flow rates. Also, some assemblies include check valves to prevent the backflow of liquid into the air piping.

Dome Diffusers

The fine pore dome diffuser was developed in Europe in the 1950s and introduced in the U.S. market in the early 1970s.[17] Long considered the standard in England and some parts of Europe, domes are now installed in a number of U.S. plants.

The dome diffuser is essentially a circular disc with a downward-turned edge. Currently, these diffusers are 18 cm (7 in.) in diameter and 3.8 cm (1.5 in.) high. The media is approximately 15 mm (0.6 in.) thick on the edges and 19 mm (¾ in.) on the top or flat surface. Domes presently are being made only of aluminum oxide.

The dome diffuser is mounted on either a PVC or mild steel saddle-type base plate. The PVC saddles are solvent welded to the air distribution piping at the factory. This minimizes adhesive problems that could occur in the center of the dome. The bolt can be made from a number of materials, including brass and stainless steel. Care must be taken when installing the dome to prevent over-tightening of the center bolt. Applying too much force can lead to immediate diffuser breakage and/or future air leakage due to bolt stretching if a nonmetallic bolt is used. A soft rubber gasket (neoprene) is placed between the diffuser and the base plate. A washer and gasket are also used between the bolt head and the top of the diffuser. Schematics of two dome diffusers are shown in Figure 3.

The slope of the headloss vs. air flow rate curve for a ceramic diffuser is very flat. It has been reported that a variation from the average of ±10 percent in the specific permeability of a diffuser can result in a 200-percent change in air flow rate for the same headloss under wet operating conditions.[18] To better distribute the air throughout the system, control orifices are placed in each diffuser assembly to create additional headloss and balance the air flow. The fastening bolt is hollowed out and a small hole drilled in the side, or the orifice is drilled in the base of the saddle. The size of the orifice is typically 5 mm (0.2 in.).

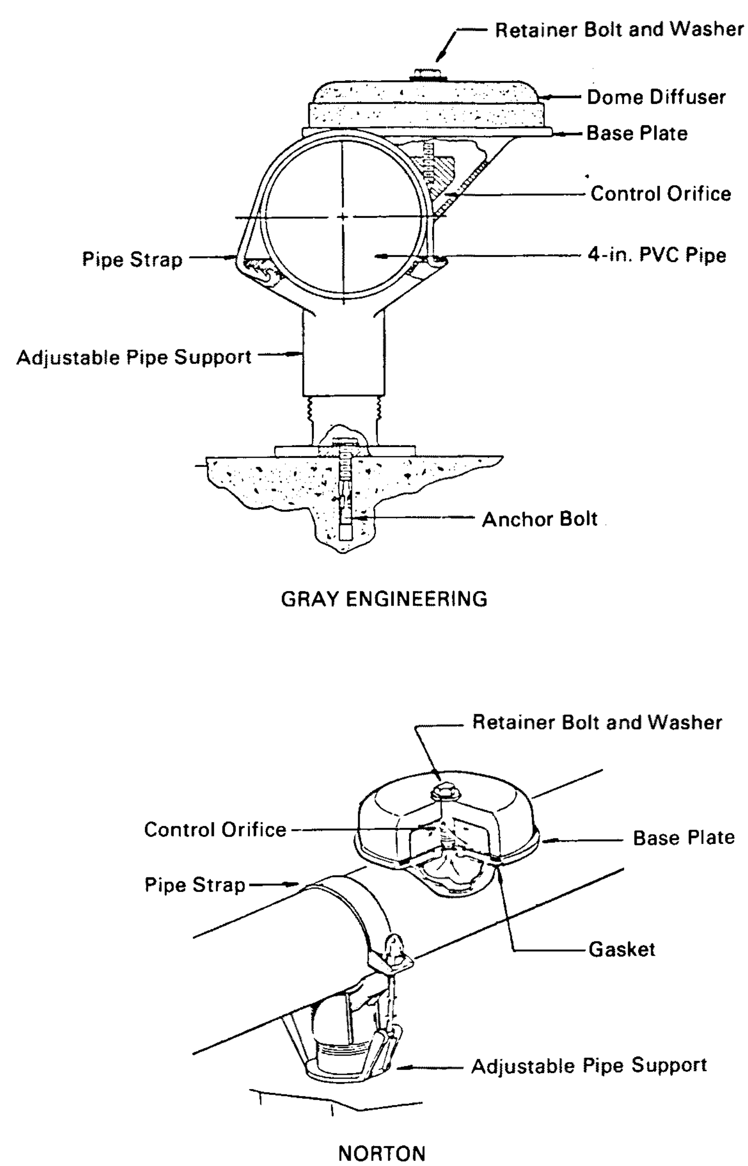


Figure 3.

Typical Ceramic Dome Diffusers

Dome diffusers are usually designed to operate at an air flow rate of 0.5 L/s (1 scfm) with a range of 0.25 to 1 L/s (0.5 to 2 scfm). In designing a system, careful consideration should be given to the desired air flow range. Testing has shown that oxygen transfer efficiency (OTE) is dependent on air flow rate per diffuser, increasing as the air flow rate decreases (refer to the next major section, Performance Characterisitcs). This performance characteristic may tempt engineers to design dome systems to operate at air flows of 0.2 to 0.25 L/s (0.4 to 0.5

scfm)/diffuser. Although favorable in terms of oxygen transfer, this practice can lead to operational problems. At low air flow rates, uniform air distribution across the entire diffuser surface may be difficult to obtain. Also, at 0.25 L/s (0.5 scfm), the headloss across the control orifice will be less than 25 mm (1 in.) water gauge. At this low rate, a different size orifice will be needed to balance air flow throughout the system. In any case, if either the entire surface or portions of individual diffusers are not discharging air, foulant deposition can begin, which could then lead to premature fouling of the entire system.

The upper limit for air flow rate for a dome diffuser is usually considered to be 1 L/s (2 scfm). Operation above this level is possible, but is not very economical (refer to the next major section, Performance Characteristics). Increasing the air flow rate above the recommended upper limit results in a continuing decrease in OTE and may require a larger control orifice.

Disc Diffusers

Disc diffusers are a relatively recent development. Discs are flat, or relatively so, and are differentiated from dome diffusers in that they do not include a downward-turned peripheral edge. While the dome design is relatively standard, currently available disc diffusers differ in size, shape, method of attachment, and type of material. Schematics of two disc diffusers are presented in Figure 4.

Disc diffusers are available in diameters that range from approximately 18 to 24 cm (7 to 9.5 in.) and thicknesses of 13 to 19 mm (½ to ¾ in.). With the exception of one design, all discs consist of two flat parallel surfaces. For the one exception, a raised ring slopes slightly downward toward both the outer edge and center of the disc. Not only is the center not quite as thick as the remainder of the disc, but it also has a lower permeability. The nonuniform profile is claimed to aid in producing uniform air flow across the entire disc surface.[19] Two of the discs also include a step on the outer edge that is impervious to air flow. This is done to reduce the area of the

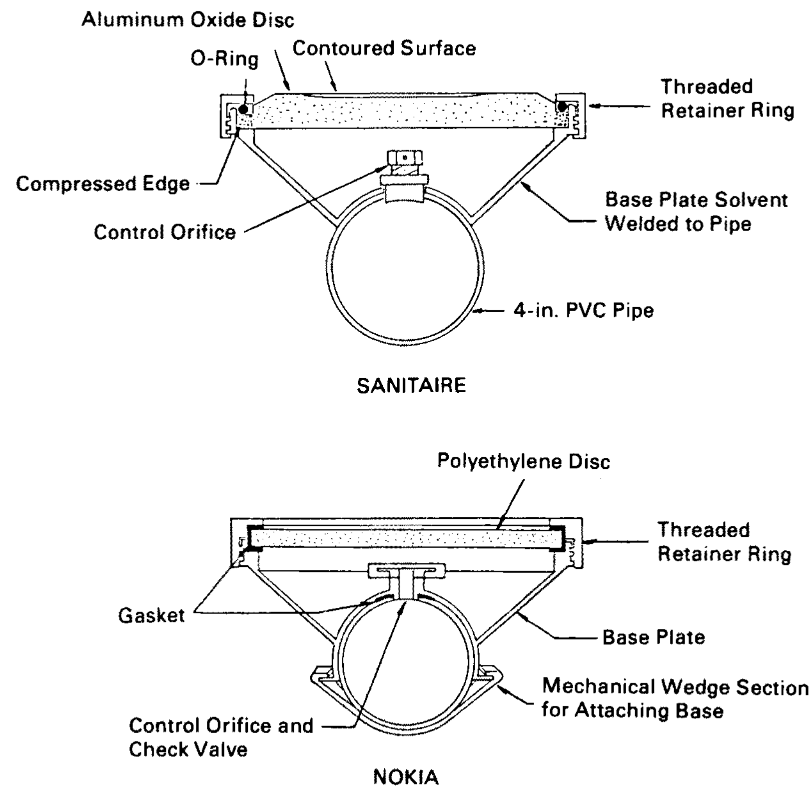


Figure 4.

Typical Disc Diffusers

vertical edge[20] and is also of benefit in attaching the media to the holder. Although the majority of disc diffusers are made from aluminum oxide, a porous PE disc is also available.

Like the dome diffusers, the disc is mounted on a plastic (usually PVC) saddle-type base plate. Two basic methods are used to secure the media to the holder: a center bolt or a peripheral clamping ring. The center bolt method is similar to that used with the domes. A soft flat rubber gasket is placed between the diffuser and base plate. The bolt assembly itself includes a washer and a gasket. The more common method of attaching the disc to the holder is to use a screw-on retainer ring. With the threaded collar, a number of different gasket arrangements are used. They include a flatgasket placed below the disc, a U-shaped gasket that covers a small portion of the top and bottom and the entire edge of the disc, and an O-ring gasket placed between the top of the disc and the retainer ring. The base plate typically includes small raised ribs to aid in obtaining an air tight seal between the gasket and the base plate.

In general, the retainer ring method of attaching the diffuser to the holder has two potential advantages over a center bolt. It has been reported that as diffusers become fouled, excessive amounts of air are discharged from the edges and the area around the center bolt washer.[17] Although not specifically documented under controlled conditions, this nonuniform air flow could reduce the OTE of the system. The retainer ring will tend to minimize these problems. The second advantage is that breakage of diffusers from over-tightening the bolt or air leakage problems from stretching a nonmetallic bolt can be eliminated.

There are two methods of attaching disc diffusers to the air piping. The first is to solvent weld the base plate to the PVC header prior to shipment to the job site. To avoid future additional costs associated with replacing sections of pipe, the original design should include all the base plates that may be needed to meet future design requirements for the system. During the early life of the plant, not all the diffusers are installed and plugs are simply inserted in the unused base plates.

The second disc diffuser attachment method uses mechanical means of attachment. The mechanical attachment can be either a bayonet-type holder that is forced into a saddle on the pipe or a wedge section that is placed around the pipe and clamps the holder to the pipe. With the exception of one manufacturer that employs the wedge clamp method of attachment and ships units preassembled, the pipe arrives at the job site with only the holes drilled. The latter technique makes shipping the pipe somewhat easier (less bulky) and can reduce damage that may occur during shipment or installation. With these types of designs, holes for additional diffusers can be predrilled and plugged or drilled at a later date.

Disc diffuser assemblies also include individual control orifices in each assembly. Designs employing the bolt method of attachment usually use a hollow bolt with an orifice drilled in its side. The other designs use either an orifice drilled in the bottom of the diffuser holder or a threaded inlet in the base where a small plug containing the desired orifice can be inserted. The diameter of the orifice is similar to that used with the dome diffusers.

Disc diffusers have a design air flow range of 0.25 to 1.5 L/s (0.5 to 3 scfm)/diffuser. The most economical operating range will, however, be somewhat dependent on diffuser size. The 18-cm (7-in.) diameter discs are usually operated in the range of 0.25 to 1 L/s (0.5 to 2 scfm), similar to the dome diffusers. For the larger discs, with diameters of 22 to 24 cm (8.5 to 9.5 in.), typical lower and upper limits are 0.3 to 0.45 L/s (0.6 to 0.9 scfm) and 1.25 to 1.5 L/s (2.5 to 3 scfm), respectively. Prolonged operation at flow rates less than 0.3 L/s (0.6 scfm) is not desirable with a large disc because insufficient air is available to ensure good distribution across the entire surface of the media. In those applications where operation above 1 L/s (2 scfm) is desirable, the control orifice should be sized accordingly so that the headloss produced does not adversely affect the economics of the system.

Clean water testing has shown that OTE is related to diffuser size.[19,21,22] A fewer number of large-diameter discs than small diameter-discs are required to achieve equivalent oxygen transfer. If the same air flow rate is applied to equal numbers of large- and small-diameter discs, the rsulting lower flux rate on the larger units will yield a slightly higher OTE. There is, however, no generally accepted ratio for comparing various size diffusers. One 23-cm (9-in.) diameter disc has been found to be approximately equivalent to 1.1 to 1.4 18-cm (7-in.) diameter discs when comparing media of a given pore size. The actual ratio is related to air flow rate and diffuser submergence.

Diffuser Layout

Plate Diffusers

Fine pore plates are most often grouted into the basin floor. Downcomer pipes deliver the air to open concrete channels below the plates. The channels act as distribution manifolds.

Plate diffusers can be installed in either a total floor coverage or spiral roll pattern. Total floor arrangements may include closely spaced rows running either the width (transverse) or length (longitudinal) of the basin or incorporated into a ridge and furrow design. Spiral roll arrangements include rows of plates typically located along one or both walls of long narrow tanks. The total floor layout will produce a higher OTE, whereas the spiral roll pattern will produce more effective bulk mixing of mixed liquor.

Tube Diffusers

Most tube diffuser assemblies include a 19-mm (¾-in) threaded nipple (stainless steel or plastic) for attachment to the air piping system. This design makes the tubes especially well suited for retrofit and/or upgrade applications since many coarse bubble diffuser systems use the identical method of attachment.

The air headers to which the tubes are mounted are usually fabricated from PVC, stainless steel, or fiberglass reinforced plastic. Carbon steel is sometimes used but is less desirable because corrosion inside the pipe can lead to fouling of the media. In most cases, the wall thickness of the pipe is not sufficient to structurally support the diffuser. Thus, threaded adapters or saddles are either glued, welded, or mechanically attached to the pipe at the points where the tubes are to be connected. The actual diameter of air headers will vary depending on the number of diffusers to be installed and the design air flow rate.

The depth of tube submergence in the basin will vary. In new installations, the tubes are usually placed as close to the floor as possible, typically within 30 cm (1 ft). In retrofit applications, the discharge pressure of the existing blowers will control the submergence. The tubes will either be installed at the same elevation as the original system or possibly at a somewhat greater distance off the floor to compensate for any increase in headloss through the fine pore media as opposed to the coarse bubble device it is replacing. The air headers may be secured to the basin floor with adjustable height, stainless steel pipe supports.

Tube diffusers are most often installed along one or both long sides of the aeration basin (single or dual spiral roll pattern, respectively). In some cases, the headers are mounted on mechanical lifts. Using this concept, the air headers and diffusers can be removed for inspection and cleaning without dewatering the basin. On the header itself, the tubes can be installed along either one side (narrow band) or both sides (wide band) of the pipe.

Tubes can also be installed in either a cross roll or total floor coverage pattern. In the cross roll design, the headers are placed across the tank width and the spacing between diffusers, 0.3 to 0.9 m (1 to 3 ft), is small in comparison to the spacing between headers, 3 to 9 m (10 to 30 ft). In the total floor coverage pattern, the distance between headers and the spacing between diffusers on the headers approach the same value. In general, total floor coverage will provide the highest OTE. The spiral roll configurations will provide better bulk mixing throughout the tank than either total floor coverage or cross roll. One potential disadvantage of the cross roll and total floor coverage designs is that the location and amount of piping required usually makes the use of mechanical liftouts impractical.

Disc and Dome Diffusers

Although their shape and operating characteristics may differ, the typical air piping and diffuser layout is identical for both disc and dome diffuser systems. The air distribution manifold should preferably be made of PVC, the compounds of which are described in ASTM D-1784 or D-3915, cell classifications 12454B and 124524, respectively (the latter is a stress-rated compound and hence a better choice). It is also recommended that the PVC be UV stabilized with 2-percent minimum TiO_2, or equivalent. The specifications, dimensions, and properties of the pipe itself conform to either ASTM D-2241 or D-3034.

The piping network is usually a nominal 10 cm (4 in.) in diameter, with the actual O.D. ranging from 10.7 to 11.4 cm (4.2 to 4.5 in.). The wall thickness is also variable, typically ranging from approximately 3.0 to 3.6 mm (0.12 to 0.14 in.). Sections of pipe are connected with gasketed, mechanical expansion joints to allow for expansion and contraction of the PVC over a temperature range of approximately 37°C (100°F). Pipe supports, usually made from PVC, are provided to secure the system to the tank floor. The support consists of a cradle or saddle and a holddown strap. The strap is either secured with a bolt or snaps into place. The pipe supports are adjustable so variations in the tank floor elevation can be compensated for. The pipe support is attached to the basin floor with a single stainless steel bolt and a concrete anchor. The PVC strap and pipe support have in the past experienced some breakage problems. To eliminate these problems, or in cases where the diffusers are to be mounted a significant distance above the tank floor, e.g., 0.6 m (2 ft), stainless steel pipe supports can be used.

Discs and domes are generally installed in a total floor coverage or grid pattern. In some cases where oxygen demand is low and mixing may control the design (near the end of long narrow tanks), the diffusers can be placed in tightly spaced rows along the side or middle of the basin to create a single spiral roll or center roll mixing pattern, respectively. The diffusers are usually mounted as close to the tank floor as possible, within 23 cm (9 in.) of the highest point of the floor being typical. As mentioned in the discussion of tube diffusers, the submergence in some retrofit applications may be controlled by the available blower discharge pressure.

Characteristics of Fine Pore Media

The following parameters have been used to characterize fine pore media:[20,23,24]

- permeability
- uniformity
- dynamic wet pressure
- strength
- chemical stability
- resistance to heat
- density (weight)

These characteristics, discussed below primarily in conjunction with porous ceramic materials, are also applicable in most cases to porous plastic materials. The flexible sheath, however, is a very different type of material. Some of the above characteristics are important in designing a flexible sheath diffuser system, while others, e.g., strength and density, are irrelevant.

Permeability

Permeability is a measure of a porous medium's frictional resistance to flow. It is an empirical rating that relates flux rate to pressure loss and pore size and/or pore volume. The permeability test procedure was developed by the ceramic manufacturing industry as a simple method of characterizing diffuser units. Permeability is usually defined as the amount of air at standard conditions that will pass through 0.09 m^2 (1 sq ft) of dry porous media under a differential pressure equivalent to 5 cm (2 in.) water gauge when tested at room temperature. The flow value obtained (scfm) under these conditions is referred to as the permeability (perm) rating.

Permeability measurement does not provide a true basis for comparison of media performance because the same permeability rating could be obtained from a diffuser with a few relatively large pores or a multitude of small pores.[5] Also, two diffusers with exactly the same pore structure would have different ratings if of different thickness.

Currently, permeability is included in specifications for porous diffusers. As best can be determined, however, the ceramic industry has not "standardized" this test procedure. The early specifications were developed for 30-cm x 30-cm (12-in. x 12-in.) plates 2.5 cm (1 in.) and 3.8 cm (1.5 in.) thick. Today, specifications are needed for products of various shapes, densities, and wall thicknesses, often of ill-defined effective area. Attempts have been made to apply the principles of the test through a parameter known as specific permeability.[25] In its determination, an applied air flow rate is measured through a diffuser mounted on a fixture similar to the fixture used in service at a pressure differential of 5 cm (2 in.) water gauge. From this measurement and the geometry of the diffusers, estimates are then made as to what the air flow (scfm) would have been at 5 cm (2 in.) water gauge differential had the dimensions of the test diffuser been 30 cm x 30 cm x 2.5 cm (12 in. x 12 in. x 1 in.).

The specific permeability procedure has served to improve the utility of this test, but does not overcome the following remaining deficiencies:

- Clamping and sealing details are not well enough defined to provide acceptable precision.
- Effective diffusion area cannot always be easily defined.
- Correction factors to account for pressure, temperature, and humidity of the air have not been developed.

Uniformity

Uniformity of individual diffusers and the entire aeration system is of extreme importance if high OTE is to be attained. On an individual basis, the diffuser must be capable of delivering uniform air distribution across the entire surface of its media. If dead spots exist, chemical or biological foulants may form and eventually lead to premature fouling of the diffuser. Also, if small areas of extremely high air flux rate are present, larger bubbles may form and OTE will increase.

A porous diffuser specification should include a requirement for testing to assure that the media will distribute air uniformly. The common practice is to select random samples from each batch during the manufacturing run. The diffusers are placed in water for a fixed period to ensure that they are saturated, then tested in a shallow basin at a predetermined air flow rate. In most cases, a visual observation is the basis for the test. This type of qualitative method is unacceptably arbitrary. Two individuals are likely to have very different definitions for what constitutes uniform air flow. In other cases, a high air flow from around the diffuser periphery may tend to mask the center of the diffuser, which may be completely dead. The diffusers tested for uniformity are usually the same ones used for permeability testing. A pass-fail criteria is established for acceptance or rejection of the batch.

A better approach to measuring uniformity is to use a quantitative technique. One such procedure actually measures the rate of air release from different areas of the diffuser.[26] With the diffuser submerged in 5 to 20 cm (2 to 8 in.) of water and at an air flow rate of approximately 10 L/s/m^2 (2 scfm/sq ft), the rate of air release is determined by measuring the displacement of water from an inverted cylinder. Based on the air volume, time, and area of the collection cylinder, a flux rate is determined. A comparison of the flux rates from various points on the diffuser surface will provide a true indication of media uniformity. Although procedures have been presented, no guidelines have yet been developed in regard to the variations between points that could be allowed before the diffuser would be rejected as nonuniform. Development of such guidelines should be undertaken.

In addition to uniformity among individual diffusers, air flow characteristics for individual grids must also be uniform. Nonuniformity of air flow in individual grids is not likely to be a problem if an adequate piping distribution system and suitably sized individual control orifices are provided.

Uniformity tests are conducted on only a relatively small number of diffusers. Even if all the random samples pass, it is still possible that some nonrepresentative diffusers may be installed in the tank. As a last check, the diffusers can be operated in the aeration tank and submerged under only a few centimeters of water. If a visual observation indicates any abnormal diffusers, they can be replaced prior to putting the basin into service if spares have been furnished.

Dynamic Wet Pressure

Dynamic wet pressure (DWP) is an important consideration in evaluating and selecting a porous media. DWP is defined as the operating headloss across diffuser media submerged in water at a specified air flow rate per diffuser.[26] As a general rule, the smaller the bubble size, the higher the DWP. While smaller bubbles may increase OTE, the additional power required to overcome the higher headloss may negate any potential savings.

The porous media currently in use have a DWP of 5 to 36 cm (2 to 14 in.) of water when operated within typical or specified air flow ranges. The specific value depends on the air flow rate, type of material, diffuser thickness, and surface properties. For ceramic and porous plastic materials, the headloss vs. air flow rate curve is linear over the typical operating range and the slope is relatively flat. DWP for these materials can vary from 5 to 30 cm (2 to 12 in.) over the same range. A fourfold increase in air flow rate of 0.25 to 1 L/s (0.5 to 2 scfm) per unit for some diffusion elements will result in only a 2.5- to 5-cm (1- to 2-in.) increase in headloss across the media itself. For the flexible sheath material, the small holes act as an orifice. Consequently, the headloss vs. air flow rate curve is steeper than for the ceramic and porous plastic media.[27] Over the typical air flow operating range of 1 to 3 L/s (2 to 6 scfm) per unit, the DWP for flexible diffusers may increase from 13 to 36 cm (5 to 14 in.).

For the ceramic and plastic materials, the majority of the DWP is associated with the pressure required to form bubbles against the force of surface tension. Only a small fraction of the DWP is required to overcome frictional resistance.[26] Thus, the thickness of the material is only a minor contributor to DWP.

DWP may be measured in the laboratory or the field.[26] It is important that porous diffusers be allowed to soak for several hours (plastic materials may require much longer) prior to testing to ensure that they are completely saturated. Since the actual headloss will be a function of the degree of water saturation in the diffusers, a slightly different curve will be obtained if the air flow is started at a low rate and is increased or vice versa. Standard practice is to purge the media at the upper flow value for a predetermined time interval (5 to 10 min), then record subsequent headloss values as the flow rate is decreased.

Because of the relationship between standard and actual air flow rates (scfm vs. acfm), the headloss in the field will be a function of diffuser submergence. If a field measurement of DWP is made, different media must be compared based on acfm.

Strength

Diffusion media must be strong enough to withstand 1) the static head of the water above the diffusers (in cases where the air supply is shut off), 2) the forces applied when attaching media to diffuser holders, and 3) stresses and shocks of reasonable handling and shipping.

Slightly different techniques have been developed to evaluate the strength of diffuser material. For discs and domes, this usually involves supporting the diffuser in a fashion similar to the final assembly, then applying a load to an area 2.5 cm (1 in.) in diameter area in the center of the diffuser. Using this method, developed primarily for the dome diffuser, acceptable compressive loads for the ceramic material range from 270 to 455 kg (600 to 1000 lb). Diffusers that use a peripheral clamping method do not require the same strength as those that employ the center bolt method of attachment.

Other Characteristics

Other characteristics of porous media are their chemical stability, heat resistance, and density. All the materials discussed (ceramic, plastic, and flexible) are resistant to the normal concentrations of chemicals used or encountered in wastewater treatment. This includes periodic exposure to strong acid solutions such as hydrochloric and formic acids used in cleaning fouled diffusers. For applications where unusual concentrations of certain chemicals are to be encountered, it is suggested that the media manufacturer be consulted and/or a testing program undertaken.

The maximum allowable operating temperatures for the various plastic materials used in the manufacture of diffusers have not been well defined. In addition to the specific compounds employed, other factors should be considered: anticipated maximum stress, environmental exposure, allowable deformation (including creep), and tolerance to changes in characteristics while in service. Further definitive work in this area is needed. In general, however, the maximum allowable operating temperature for plastics will fall in the range of 38 to 93°C (100 to 200°F).

On the other hand, ceramic materials can safely tolerate temperatures up to 815°C (1500°F). The maximum allowable operating temperature for ceramics, therefore, is not a concern in wastewater treatment applications.

Density is of importance mainly in situations where the diffusers are to be lifted out of the tank. The ceramic material has a density that ranges from approximately 1600 kg/m^3 (100 lb/cu ft) for silica to 2325 kg/m^3 (145 lb/cu ft) for aluminum oxide.[20] The porous plastic material in contrast has a typical density of only 560 to 640 kg/m^3 (35 to 40 lb/cu ft).[13]

Performance Characteristics

The purpose of this section is to provide the reader with information and reference sources regarding clean water and process water performance of the aeration devices described in the preceding section. In some cases, performance characteristics of devices not described in the preceding section are included here for comparative purposes.

Background

In the late 1960s and early 1970s, consulting engineers began specifying that clean water performance tests be conducted by the aeration equipment suppliers as a means of verifying aerator performance. Various engineers developed their own testing criteria.

In April 1978, a Workshop Toward An Oxygen Transfer Standard[28] cosponsored by the U.S. Environmental Protection Agency (EPA) and the American Society of Civil Engineers (ASCE) was held in an effort to obtain consensus standards for the evaluation of aeration devices in both clean and process waters. The outcome of the workshop was the formation of an Oxygen Transfer Standards Committee under ASCE.

Between 1978 and 1984, this Committee developed and adopted an ASCE Standard for the Measurement of Oxygen Transfer in Clean Water[29] and evaluated several process water test methods.[30] Progress with respect to the development of standardized test methods for the evaluation of aeration devices in clean water has been substantial. Due to the wide variety of experience in clean water testing and the desirability of incorporating that experience into the Standard, several years passed prior to its publication in July 1984.

Clean Water Performance

The following discussion summarizes clean water performance data on fine pore diffusion devices. Some but not all of the data were generated using the current ASCE recommended clean water standard.[29] Thus, the oxygen transfer results summarized in this subsection reflect the utilization of the current nonlinear least squares method of analysis as well as a prior procedure using the linear least squares log deficit analysis.[29] The latter method permitted data truncation. Both methods produce comparable results under ideal testing conditions. Every effort has been made to screen the data reported herein and to omit data of questionable validity.

The results of clean water oxygen transfer tests are reported in a standardized form as either standard oxygen transfer efficiency (SOTE), standard oxygen transfer rate (SOTR), or standard aeration efficiency (SAE) as shown in Table 1. The standard conditions for reporting clean water tests are also delineated in Table 1. All data reported in this section are given as standard transfer values unless otherwise noted.

Examination of Table 1 indicates that one of the critical parameters required for the calculation of oxygen transfer rates is the equilibrium DO saturation concentration, C^*_∞. For submerged aeration applications, C^*_∞ is significantly greater than the surface saturation value, C^*_s, tabulated in most standarad tables.[30] It is, therefore, necessary to either calculate[30] C^*_∞ or measure[29] it during clean water tests. The value of C^*_∞ is primarily dependent on diffuser submergence, diffuser type, tank geometry, and gas flow rate. One of the more comprehensive evaluations of C^*_∞ in clean water tests was reported by Yunt et al.[31] Typical results for a variety of diffuser types at selected submergences are presented in Figure 5.

The performance of diffusers under clean water test conditions is dependent on a number of factors in addition to those standardized in the calculations of SOTE, SOTR, and SAE. Among the important factors are:

- diffuser type (material, shape, and size),
- diffuser placement and density (area served per diffuser),
- gas flow rate per diffuser, and
- diffuser submergence and tank geometry.

Typical SOTEs for fine pore diffused air systems are presented in Table 2. These data are reported for a diffuser submergence of 4.6-m (15-ft). The effect of diffuser type, placement, and air flow rate per diffuser are clearly delineated from this summary

Table 1.

Standard Equations for Clean Water Oxygen Transfer Tests[29]

Standard Conditions:

DO	= 0.0 mg/L	α = 1.0
Temperature	= 20°C	β = 1.0
Pressure	= 1.00 atm	

Standard Oxygen Transfer Rate (SOTR) - mass/time

$$SOTR = K_La_{20}\, C^*_{\infty 20}\, V$$

Standard Oxygen Transfer Efficiency (SOTE)

$$SOTE = \frac{\text{Mass Transferred}}{\text{Mass Supplies}} \times 100$$

$$= \frac{SOTR}{Y_R\, q_s\, \rho}$$

Standard Aeration Efficiency (SAE) - mass/time, power

$$SAE = \frac{SOTR}{\text{Power Input (specified as delivered, brake, wire, or total wire)}}$$

K_La = apparent volumetric mass transfer coefficient in clean water, time^{-1}

K_La_{20} = K_La @ 20°C, time^{-1}

V = volume of water, length^3

Y_R = mole fraction of oxygen delivered

ρ = density of oxygen at actual temperature and pressure, mass/length^3

q_s = volumetric air flow rate, length^3/time

$C^*_{\infty 20}$ = equilibrium DO saturation concentration attained at infinite time for given diffusion device at 20°C and 1 atm, mass/length^3

of eight different clean water studies. In general, it can be observed that ceramic domes and discs demonstrate slightly higher clean water transfer efficiences than typical porous plastic tubes or flexible sheath tubes in a grid placement. Both tubes and discs/domes are significantly superior to all coarse bubble placements. Within a given diffuser type, spreading the diffusers more uniformly along the tank bottom area (moving from single spiral roll to dual spiral roll to grid) tends to improve clean water performance.[39] The effects of tank and diffuser geometry on diffuser performance have been reported by numerous investigators. One of the early, notable studies by Bewtra and Nicholas[32] in a 1.2-m (4-ft) wide x 7.3-m (24-ft) long test tank using coarse bubble spargers and fine pore Saran tubes demonstrated similar effects of geometry.

Figure 6, derived from the data contained in the Table 2 references, demonstrates the effect of air flow rate per diffuser on SOTE. SOTEs for domes and discs in a grid placement decrease significantly with increased air flow. A somewhat smaller effect is evident for porous plastic media and flexible tubes, while coarse bubble patterns are relatively unaffected by gas flow rate with some indication of increasing SOTE at the higher gas flows. Very similar patterns were reported in 1964 by Bewtra and Nicholas[32] for coarse bubble spargers and fine pore tubes.

The effects of water depth on oxygen transfer performance for several types of diffusers are illustrated in Figures 7 and 8. Although these data are for one specific test tank and air flow rate,[31] they are representative of the typical effects of depth on performance. In general, SOTE values will increase with increasing depth since mean oxygen partial pressure is higher (thereby resulting in a greater driving force) and opportunity is present for longer bubble residence time in the aeration tank. The SAE, however, remains relatively constant (or may decrease) for fine pore diffusers as depth increases since power requirements to drive the same volume of air through diffusers at the greater depths will increase. In contrast, the coarse bubble diffusers exhibit a gradually increasing SAE with increasing depth, while not reaching the overall efficiencies demonstrated by the fine pore systems.

The clean water SOTE performance data in Table 3 are for PE plastic tubes. The data are typical of fine pore diffusers, exhibiting increasing OTE with increasing diffuser density (moving from single spiral roll to dual spiral roll to grid). Popel[35] observed that increased diffuser density in grids decreases upward flow velocities and, therefore, increases the retention time of bubbles. He reported on one field test of a countercurrent aeration system with a rotating bridge. The aeration channel had a width of 11 m (36 ft) and a depth of 3.2 m (10.5 ft). SOTEs of 5.6 to 6.9 percent/m (1.7 to 2.1 percent/ft) of submergence were reported at air flow rates of 1.5 to 3 L/s (3 to 6 scfm)/diffuser.

Typical performance of a flexible sheath diffuser[37] is summarized in Table 4. This diffuser also exhibits a decreasing transfer efficiency with increasing air flow rate. The effect of diffuser placement is also evident. The increase for quarter-point placement vs. single spiral roll placement in a rectangular basin is greater than for the mid-width placement. Bewtra and Nicholas[32] found that a dual spiral roll placement was more efficient than a mid-width placement in a rectangular tank.

The clean water SOTEs of disc/dome grid systems are illustrated in Table 5. This type of system has produced the highest transfer efficiencies reported for fine pore devices. The density of placement is greater than in the tube grid systems, and the air flow rates per diffuser are lower. Huibregtse et al.[21] reported a slightly increased transfer efficiency with a 24-cm (9.4-in.) diameter disc vs. an 18-cm (7-in.) diameter dome. The

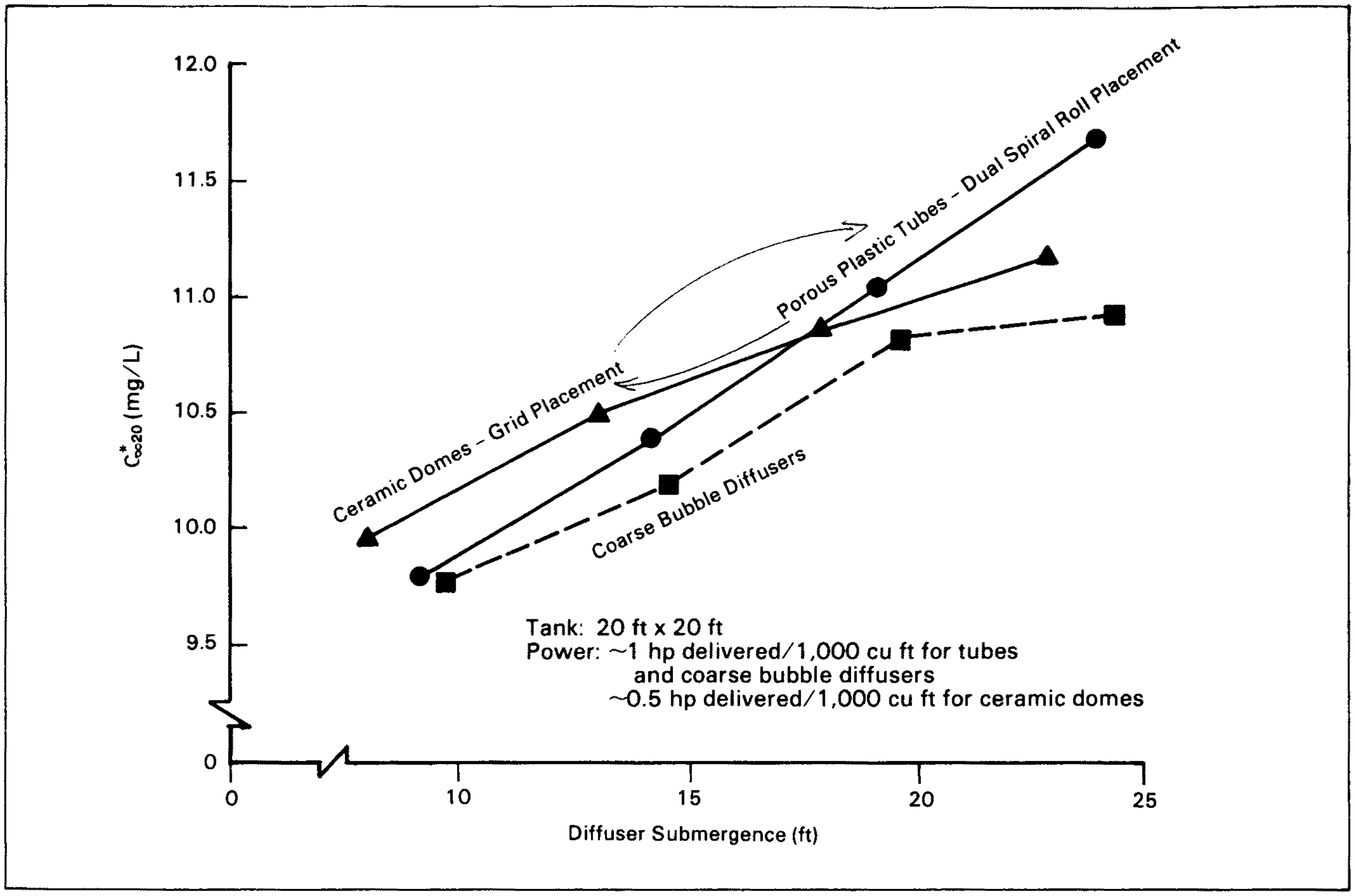


Figure 5.

Effect of Diffuser Submergence on $C^*_{\infty 20}$ for Three Diffuser Types

Table 2.

Clean Water Oxygen Transfer Efficiency Comparison for Selected Diffusers

Diffuser Type & Placement	Air Flow Rate (scfm/diffuser)	SOTE (%) at 15-ft Submergence	Reference
Ceramic Discs-Grid	0.6-2.9	25-36	21
Ceramic Domes-Grid	0.5-2.5	27-39	21,31,33,34
Porous Plastic Tubes			
Grid	2.4-4.0	28-32	35
Dual spiral roll	3.0-9.7	18-28	21,31,36
Single spiral roll	2.0-12.0	13-25	21,36
Flexible Sheath Tubes			
Grid	1-4	22-29	37
Quarter points	2-6	19-24	37
Single spiral roll	2-6	15-19	37
Coarse Bubble Diffusers			
Dual spiral roll	3.3-9.9	12-13	31,38
Mid-width	4.2-45	10-13	31,38
Single spiral roll	10-35	9-12	31,38

increase was in the range of 5 to 15 percent, varying with depth. He attributed the increase to a 70-percent increase in effective surface area with the discs. He also indicated that the larger surface area limits the degree of bubble coalescence. Houck and Boon[17] and Yunt and Hancuff[27] have also reported a similar relationship between dome/disc diameter and oxygen transfer per diffuser.

The data from the references in Table 5 are plotted in Figure 9 to show the general trend between SOTE and diffuser density and air flow rate per diffuser. Increasing diffuser density increases SOTE, and increased air flow rates for a given diffuser density decreases SOTE.

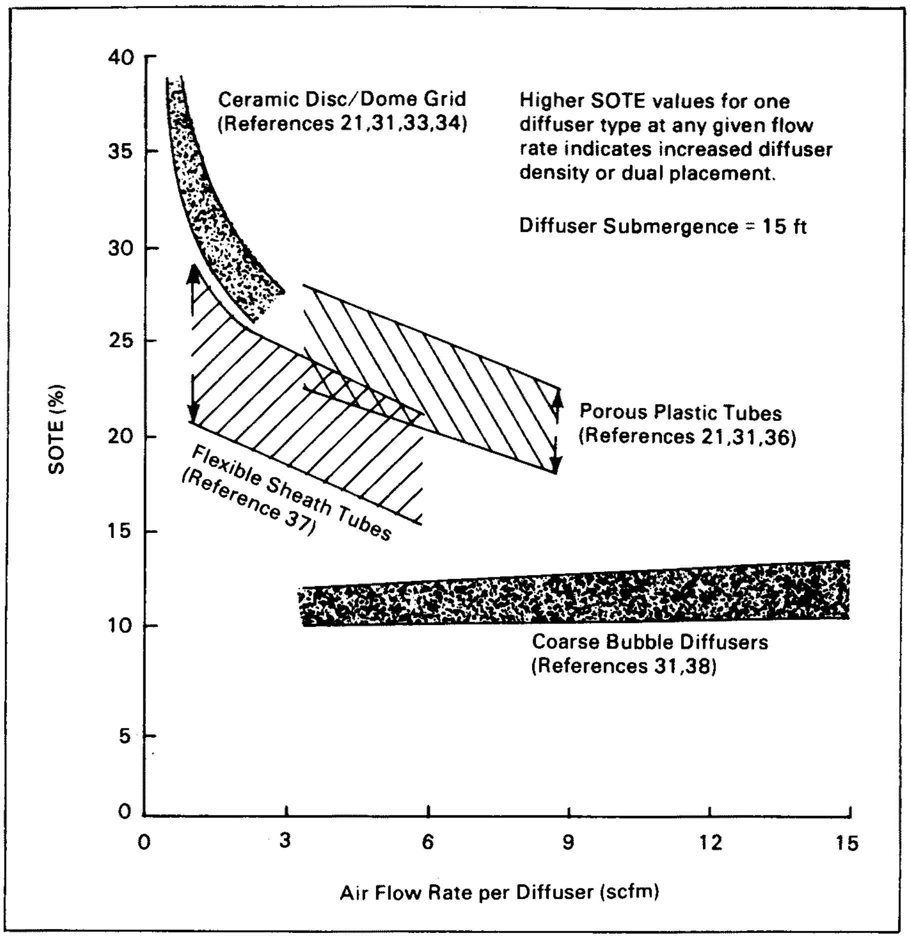


Figure 6.

Effect of Air Flow Rate per Diffuser on SOTE for Four Diffuser Types

Process Water Performance

Development of a clean water standard was the springboard from which additional studies were undertaken by the ASCE Oxygen Transfer Standards Committee to evaluate a number of test procedures used for estimating oxygen transfer under process conditions. Substantial process oxygen transfer data have been collected using these procedures over the past few years. The standard clean water transfer rate (SOTR), as measured at 20°C with a zero residual DO concentration, may be related to actual field conditions (OTR_f) according to the following equations:[40]

$$OTR_f = \alpha SOTR \; \frac{\beta \tau \Omega C^*_{\infty 20} - C}{C^*_{\infty 20}} \; \theta^{T-20}$$

where: $\alpha = \dfrac{K_L a_f}{K_L a}$

$$\beta = \frac{C^*\,(\text{field})}{C^*\,(\text{clean water})}$$

$$\tau = \frac{C_{sT}}{C_{s20}}$$

$$\Omega = \frac{P_b + d_e - P_{v20}}{P_s + d_e - P_{v20}}$$

$$\theta^{T-20} = \frac{K_L a_T}{K_L a_{20}}$$

$K_L a_f$ = apparent volumetric mass transfer coefficient in process water

C^* = equilibrium DO saturation concentration corresponding to a given partial pressure of oxygen, temperature, and volume

C_{sT} = surface DO saturation at 1 atm total pressure, 100 percent relative humidity, and temperature T

C_{s20} = surface DO saturation concentration at 1 atm total pressure, 100 percent relative humidity, and a temperature of 20°C

P_b = base pressure

P_s = standard pressure of 1 atm

P_{v20} = vapor pressure of water at a temperature of 20°C

d_e = effective saturation depth at infinitive time

Before 1981, the methods used to evaluate aerator performance under process conditions were inconsistent and coherent data on process water performance were extremely limited. Alpha is probably the most controversial and reasearched parameter used in translating clean water oxygen transfer data to actual field performance. Variables affecting the value of alpha include aerator type, nature of wastewater contaminants, position within the treatment scheme, process loading rate, bulk liquid DO, water depth, and air flow rate. Coherent data on alpha values for various aeration devices are limited. Alpha values of 0.2[41] to 1.53[42] have been published. Because much of the reported alpha data was obtained from bench-scale units (which did not properly simulate mixing and $K_L a$ levels, aerator type, water depth, and/or the geometry effects of their full-scale counterparts), these data are of questionable value. Reliable full-scale test procedures for use under process conditions, coupled with clean water performance data are required to overcome these deficiencies. Several references on this subject provide useful information.[40,43-45]

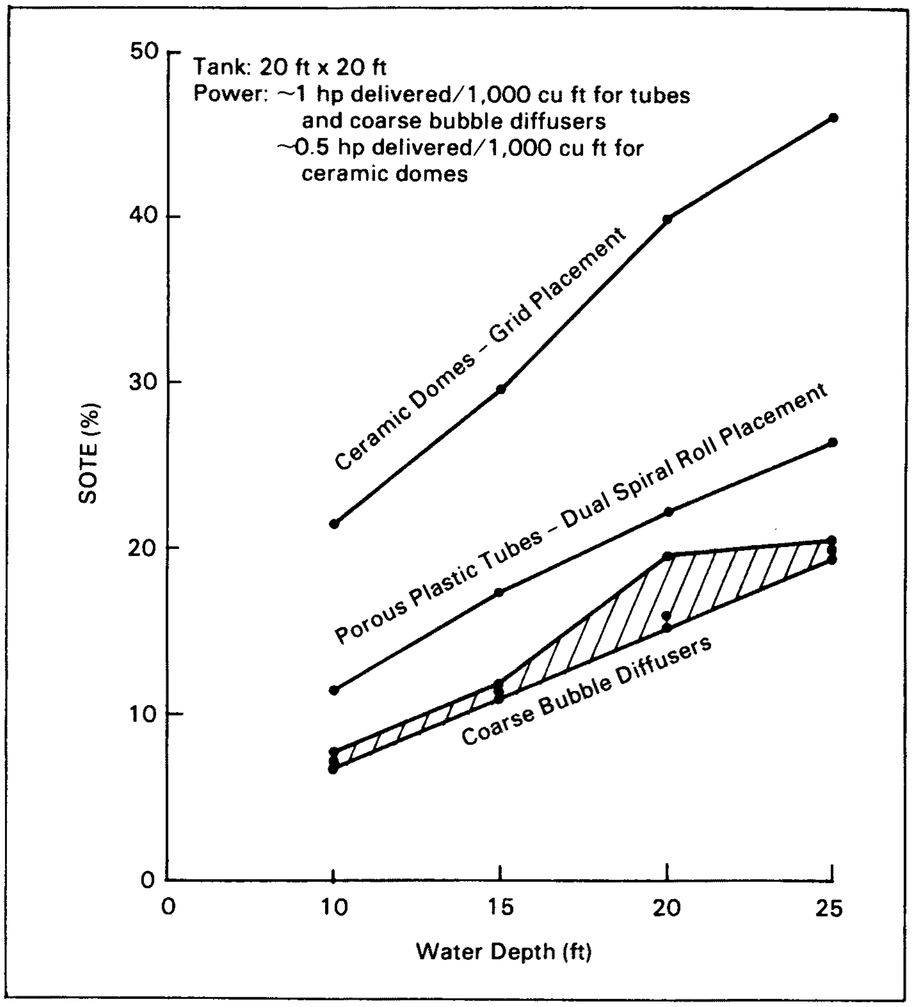


Figure 7.

Effect of Water Depth on SOTE for Three Diffuser Types[31]

Test Methods

In 1981, the ASCE Oxygen Transfer Standards Subcommittee undertook a seven-site study to evaluate, in parallel, four principal methods for estimating oxygen transfer under process conditions.[46] These methods include the steady state method, the nonsteady state method, an off-gas analysis procedure, and two inert gas tracer techniques.

Those test methods requiring that the rate of DO change be zero at any given point in the test volume are referred to as steady state methods; those depending on a rate of DO change with time are called nonsteady state tests. In both cases, however, it is necessary that the wastewater influent flow rate and characteristics, as well as the test volume, oxygen uptake rate, and field oxygen transfer coefficient, K_La_f, be constant. In addition, basin DO values must be in excess of 1 mg/L for carbonaceous oxidation and 2 mg/L for nitrification to obtain valid uptake data.

To overcome the problem of maintaining steady load and K_La_f conditions and to ensure better precision, wastewater flow may be discontinued during a test. This method of testing is referred to as the batch or batch endogenous technique as contrasted with continuous flow methods. Batch testing, however, suffers the critical disadvantage that it does not realistically measure true field transfer rates of alpha values under normal loading conditions. For this reason, it was not included as one of the methods studied by the Oxygen Transfer Standards Committee.

In contrast to the steady state and nonsteady methods, the off-gas and inert gas tracer procedures do not require steady process loads, do not need positive basin DO, and do not require the measurement of oxygen uptake rate. Accordingly, these procedures can be more effective in measuring oxygen transfer in the field under actual process conditions than the steady state and nonsteady state methods.

Of the four methods discussed, the off-gas procedure is unique in that it measures the fraction of oxygen transferred from the gas stream directly, whereas the other methods (the liquid phase methods) determine K_La_f. For those methods relying on K_La determinations, errors in applied air flowrates proportionally affect computations of OTE and oxygen transfer rate. Since the off-gas procedure measures OTE directly as well as the rate of gas flow leaving the liquid surface at each test position, accurate plant air flow measurement is not critical. Accurate plant air flow measurement is desirable, however, to validate that a representative gas sampling was obtained. Where off-gas OTE results must be converted to standard conditions, accurate measurements of basin temperature and DO must be made.

Selected factors affecting the estimation of OTE are identified in Table 6. The inert gas tracer methods have the broadest applicability since they may be used for both mechanical and diffused air devices. The steady state and nonsteady state methods generally are not applicable to plug flow reactors where alpha, DO, backmixing, and applied air flow rate vary throughout the basin. The tracer techniques, though less affected by the above factors, also are not ideally suited for use in plug flow regimes. The questionable impact of variable gas flow rate and K_La_f throughout the basin, along with the need for accurate knowledge of local air flow rates throughout the basin, can adversely affect the accuracy of the tracer techniques.

The off-gas procedure, which is capable of measuring localized performance throughout the basin with respect to OTE, air flow rate,

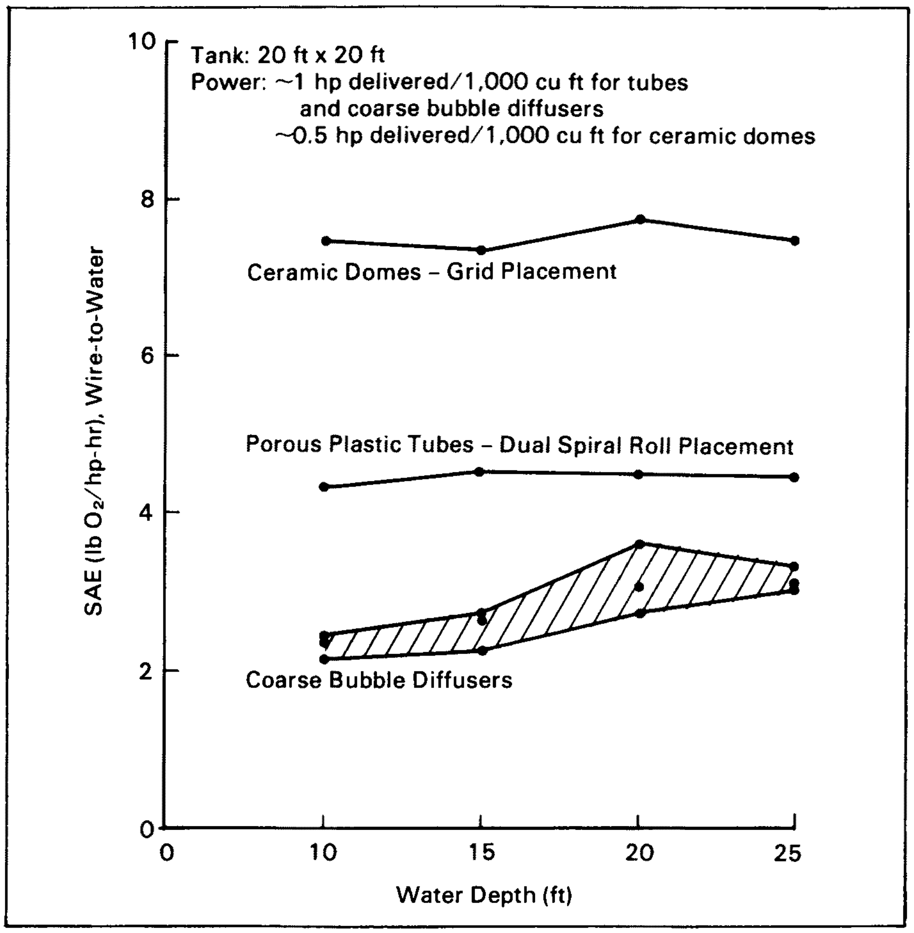


Figure 8.

Effect of Water Depth on SAE for Three Diffuser Types[31]

Table 3.

Clean Water Oxygen Transfer Efficiencies of Porous Plastic Tubes

Placement	Air Flow (scfm/diffuser)	SOTE (%) at Water Depth 10 ft	15 ft	20 ft	Reference
Grid*	2.4-4.0	--	28-32	--	35
Dual Spiral Roll	3.2-6.3	11-16	17-24	22-32	21,31,36
	9.0-9.7	10-14	15	21-26	21,31,36
Single Spiral Roll	2.0-6.7	12-15	15-20	22-25	21,31,36
	8.0-12.0	10-15	10-17	22	21,31,36

*Placement density = 7.7 sq ft/tube. Tank is 14.4 ft x 108.2 ft.

and driving force, is well suited for evaluating the process water performance of diffused aeration systems in plug flow as well as complete mix tanks. As with all test methods, representative sampling of the test basin is essential with this procedure if an accurate appraisal of system performance is to be obtained.

Factors Affecting Performance

The performance of diffused aeration systems under process conditions is affected by a myriad of factors, some of the more important of which are

- wastewater characteristics,
- process type and flow regime,
- loading conditions,
- basin geometry,
- diffuser placement and performance characteristics,
- changes in performance due to fouling,
- mixed liquor DO control and air supply flexibility,
- mechanical integrity of the system,
- operator expertise, and
- quality of preventive maintenance.

Previous Water Pollution Control Federation (WPCF) Manuals of Practice (MOP) on Aeration,[5,7] along with the upcoming revised MOP No. 5 are good general references on the above factors. To minimize life cycle costs of an aeration system, all of these factors must be considered during design.

The areas of greatest concern in process water oxygen transfer performance are wastewater characteristics, process type and flow regime, and loading conditions. They all have a significant effect on the alpha profile of a system, DO control, and changes in aerator performance with time due to diffuser fouling. These factors are discussed after the following process water data base presentation.

Process Water Data Base

As indicated earlier, a substantial data base exists for the clean water performance of the diffused aeration systems considered in this report. The process water oxygen transfer data base is much more limited. Since oxygen transfer performance under field conditions is really the ultimate goal, expansion of the latter data base is needed. The following summarizes and discusses available data for the fine pore diffusion systems previously described. A few aeration systems not previously described are also examined for comparative purposes.

Process water oxygen transfer performance data from 13 evaluations at various sites employing a variety of aeration

Table 4.

Clean Water Oxygen Transfer Efficiencies of Flexible Sheath Tubes[37]

Placement	Air Flow (scfm/diffuser)	SOTE (%) at Water Depth		
		10 ft	15 ft	20 ft
Floor Cover (Grid)	1-4	14-18	21-27	29-35
Quarter Points	2-6	13-15	18-22	24-29
Mid-Width	2-6	9-11	15-18	23-17
Single Spiral Roll	2-6	7-11	14-18	21-28

Table 5.

Clean Water Oxygen Transfer Efficiencies of Ceramic Disc/Dome Grid Systems

Diffuser Density (sq ft/diffuser)	Air Flow (scfm/diffuser)	SOTE(%) at Water Depth			Reference
		10 ft	15 ft	20 ft	
Disc-9.4 in.					
6.4	0.9-3.0	20-22	31	34-37	21
4.1	0.8-2.9	21-24	30-34	35-41	21
3.2	0.7-2.6	22-25	31-34	38-41	21
Dome-7 in.					
5.6	0.5-2.0	--	25-31	28-40	33
4.2-4.4	0.5-2.5	16-23	25-32	30-41	33,34
3.2-3.3	0.5-2.0	20-24	27-37	31-44	21,31,33
2.2-2.5	0.5-2.5	17-23	27-35	33-47	33,34
1.5	0.5-2.5	18-26	27-34	--	34

systems are presented in Table 7. Each data set represents the observed performance of a particular system over a period of several hours only and is not suitable for the design of similar systems. The intent of this table is to give the reader a general feeling for the range in performance of the systems listed under a variety of operating conditions.

The oxygen transfer data were all collected using the off-gas test procedure. Apparent values of alpha were estimated from clean water performance data for similar tank geometry, air flow rate per diffusion unit, and diffuser placement. Since the performance of most porous diffusion devices is likely to change with time, the term "apparent alpha," α_a, has been adopted to distinguish between differences in clean and process water performance for cases where the diffusers are process tested at a condition of undetermined fouling (α_a) vs. those where they are process tested new or just after cleaning (α). The latter condition measures the alpha value due to wastewater characteristics only. In all cases, the OTE_f (field results) values have been converted to α_aSOTE values, i.e., to 20° and zero residual DO.

The first three data sets originated from off-gas testing at Madison, Wisconsin.[47-49] The ceramic grid data (the first data set) represent the overall performance of a three-pass system. OTE_f, air flux rate (air flow per unit surface area of tank), and residual DO profiles are shown in Figure 10 as a function of tank length. Values of apparent alpha with position in the basin are plotted in Figure 11. Apparent alphas were estimated from clean water data having the same diffuser density, air flux rate, and liquid submergence as the grids from which the off-gas data were collected. Due to variable flux rates and diffuser densities, the OTE_f values in Figure 10 do not accurately reflect changes in apparent alpha along the tank. At this facility, the apparent alpha varies from about 0.4 at the tank inlet to near 1.0 at the tank outlet. A reduction in apparent alpha occured at each point of primary effluent addition.

The second Madison data set for ceramic and SAN plastic tubes, applied in a dual spiral roll configuration, represents performance for the first pass of a three-pass system (Figure 12). Passes two and three, represented by the third data set, are equipped with wide-band, fixed-orifice, coarse bubble diffuser, also oriented in a dual spiral roll placement. The higher relative alpha values of the latter two passes are strongly influenced by the favorable position of these passes at the middle and effluent end of the process train compared to the lead-pass position of the ceramic and SAN plastic tubes. This relationship of alpha to tank position or degree of treatment is similar to that observed for the first Madison data set (Figure 11).

The two data sets for Whittier Narrows, California represent approximately 9 months of operation.[47,48] The two systems for which data are presented were part of a three-system field oxygen transfer evaluation conducted by the Los Angeles County Sanitation Districts (LACSD) for EPA in parallel trains.[50]

These data sets compare the performance of a ceramic grid system to that of a jet aeration system where the jets were installed on one side of the basin along the entire tank length with the nozzles being directed across the basin floor in a reverse spiral roll. Figure 13 is a plot of apparent alpha for each system vs. position from the inlet end. The ratio of apparent alpha values varies with tank length, decreasing toward the effluent end of the tank.

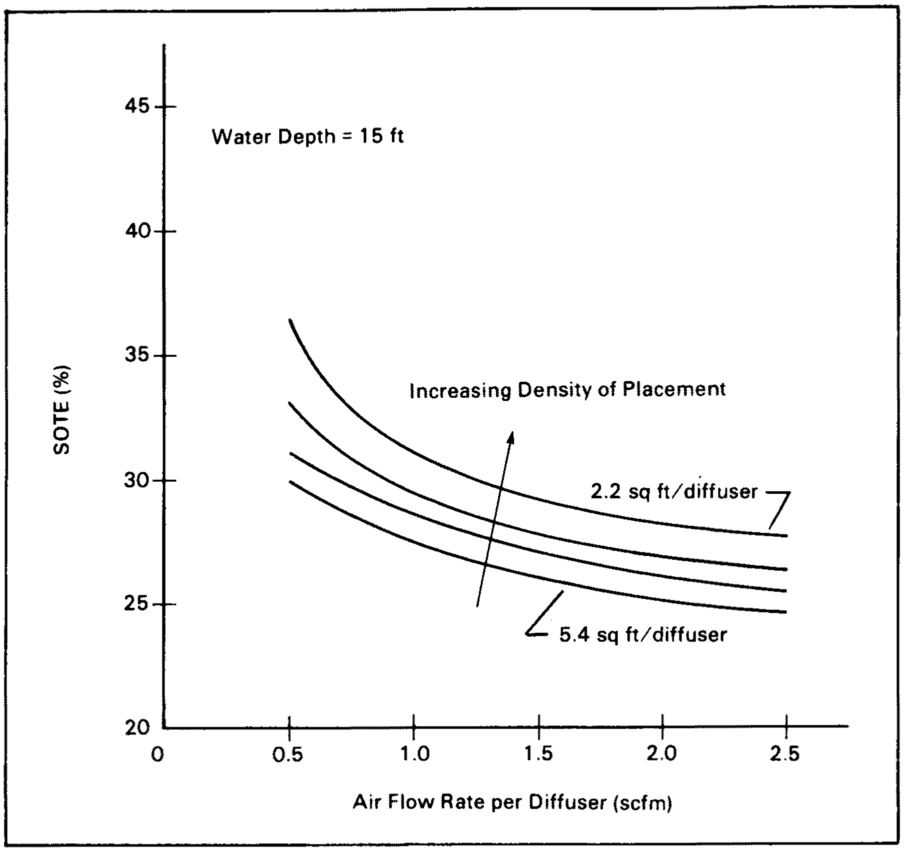


Figure 9.

Effect of Diffuser Density on SOTE for Ceramic Disc/Dome Grid Configurations[21]

Of particular interest are the apparent alpha values near the discharge end of these basins as contrasted to those observed at Madison, Wisconsin. The terminal apparent alpha of the ceramic grid system at the Whittier Narrows facility was approximately 0.6 vs. almost 1.0 for Madison's ceramic grid system. The presence of nonbiodegradable surfactants is one explanation for the low apparent alphas at Whittier Narrows. Other possibilities include high process loadings, low DO operation, and significant diffuser fouling. This observation illustrates the dangers of extracting data from specific sites for general design purposes. Each treatment facility has unique characteristics that must be considered individually.

The Brandon, Wisconsin, data set depicts performance of a 9.1-m (30-ft) long x 4.6-m (15-ft) wide x 4.6-m (15-ft) deep completely mixed aeration tank using jet aerators at two different air flow rates.[48,49] This municipal facility treats a combination of domestic and industrial wastewaters.

In contrast, the Orlando, Florida, aeration system,[51] which employs wide-band, fixed-orifice coarse bubble diffusers, treats domestic wastewater only. This system is currently being retrofitted with a ceramic grid system in an effort to improve aeration efficiency and increase aeration capacity.

The data shown for Seymour, Wisconsin,[52] a site analyzed by Houck[53] in his North American survey of disc and dome diffuser systems and also studied by Vik et al.,[54] were collected on a lightly loaded system with a sludge retention time in excess of 25 days at the time of the tests.

The two data sets from Lakewood, Ohio ,[55] demonstrate the relative performance of two parallel basins, one whose diffusers had recently been cleaned and the other which had been operating for approximately I year with no diffuser cleaning. The entire system was retrofitted with ceramic disc diffusers in a grid configuration during 1982 and 1983. In this instance, the uncleaned system as found was performing at a mean weighted αaSOTE of 8.9 percent vs. 14.5 percent for the cleaned system. During the 1-year operating period, it appears that oxygen transfer performance deteriorated by roughly 40 percent. Part of this reported performance deterioration may have been due to fouling resulting from several periods of air interruption to make necessary modifications to the air supply piping during the retrofit process.

The last two data sets provide information on new ceramic grid and static aerator systems that were tested on brewery wastes within the same completely mixed basin.[56] Of interest is the relative performance of both systems as measured by oxygen transfer and apparent alpha data. The ratio of the mean weighted apparent alphas of the static aerator system to that of the ceramic grid system was observed to be 0.50/0.37 = 1.35. This ratio is not considered appropriate for design since, among other things, the levels of alpha observed in this industrial wastewater application are lower than usually encountered. The respective ratio of α_aSOTE values was 7.4/14.2 = 0.52.

Data are presented in Table 8 from a Madison, Wisconsin, oxygen transfer field evaluation for the last pass of a three-pass system employing selected tubular diffusers in a dual spiral roll configuration.[47] The aerator layout is depicted in Figure 14. The off-gas test procedure was used in collecting the OTE_f data. Since alpha approached unity at this tank location, direct use of the data is not suitable for design purposes. The relative performance of the new and used ceramic tubes and the used SAN plastic tubes indiactes the significance of fouling. The used ceramic and SAN plastic tubes were in service continuously for about 3 years in a different tank prior to relocation for this test. It should be noted that analysis of multiple systems within a given tank cannot be conducted by any other technique than off-gas analysis. Known

Table 6.

Selected Factors Affecting Oxygen Transfer Field Testing for Estimation of Oxygen Transfer Efficiency[46]

Factors	Oxygen Transfer Test: Steady State	Nonsteady State	Off-Gas	Inert Gas Tracers
Sensitivity To				
Variations in				
● Influent wastewater flow rate	-	-	+	+
● Oxygen uptake rate	-	-	+	+
● Alpha	-	-	+	+
● DO concentration	-	-	+	+
● Product of air flow rate x K_La	-	-	+	0
Accurate measure of				
● Oxygen uptake rate	-	+	+	+
● DO concentration	-	-	+	+
● DO saturation value	+	+	1	+
● Air flow rate	-	-	1	-
● Other	+	+	2	3
Costs				
Manpower	+	0	0	0
Analytical	+	+	0	-
Capital investment	+	+/0	0	-
Calculations	+	0	0	0
Estimated Precision	-	0	+	+

1 Calculate OTE directly.
2 Requires accurate measurement of CO_2 in gas.
3 Requires accurate estimate of the ratio of K_{tracer}/K_La.
\+ Positive response (e.g., not sensitive, less costly, more precise, easier).
0 Intermediate response.
\- Negative response.

available data on tube and flexible sheath systems are scant, and additional reliable information would be of significant value.

On the basis of the data presented in Table 7, it appears that the differences between apparent alpha values for ceramic grid fine pore diffusers and apparent alpha values for other more turbulent systems such as jet aerators and static aerators may not be as great as previously reported in the literature.[57] In addition, the overall average apparent alpha values presented in Table 7 and elsewhere[58-60] for a variety of aeration devices are lower than many alpha values historically used for design purposes.

A recent study at Rye Meads, United Kingdom,[61] demonstrates the impact of process goals relative to aeration efficiency. In this study, optimization of the nitrification process in conjunction with an initial anoxic zone, tapering diffuser density to meet oxygen demand, and the use of automated DO control resulted in an overall aeration efficiency of 2 kg O_2/kWh (3.3 lb/wire hp-hr) vs. 1.2 kg O_2/kWh (2.0 lb/wire hp-hr) for an unmodified control basin. A third parallel train employing tapered air and DO control in a non-nitrifying operational mode averaged about 1.4 kg O_2/kWh (2.3 lb/wire hp-hr) during the study phase. Proper placement of the ceramic dome diffusers, automated DO control, and level of treatment were identified as essential elements of Rye Mead's aeration efficiency optimization.

Another factor of concern was observed in a recent, long-term study of ceramic grid systems[62] where the slope of log OTE vs. log applied air flow rate under process conditions had a significantly steeper negative slope with increasing air flow rate than observed under clean water conditions. An illustration of this observation is shown in Figure 15. Other investigators,[61] however, have not observed this phenomenon.

Figure 15 shows that the slope of the log OTE vs. log applied air flow rate curve of a new or clean porous diffuser is very different from that of a fouled or partially fouled unit. Danley[63] has observed that, as diffusers become biologically fouled, the effective pore area of the diffusers decreases drastically. Typical plant practice is to operate diffusers at the same or greater specific air flow rate over a period of time. Since the effective pore area has been greatly reduced by the accumulated foulants, the actual air flow rate per operating pore correspondingly increases. Generalizations on this relationship cannot be made at this time, however, due to the lack of an adequate data base.

The data described above represent a diverse cross section of process performance for selected oxygen transfer devices under a variety of operating conditions. No attempt has been made here to correlate oxygen transfer performance to process type, process loading, wastewater characteristics, and other factors. It is evident that gaps in the current data base still exist for which additional, in-depth study is needed to address designer concerns.

Table 7.

Process Water Oxygen Transfer Efficiency Comparison for Selected Aeration Systems

Site	System	Flow Regime	α_a SOTE (%) Mean	α_a SOTE (%) Range	Diffuser Submergence (ft)	Variation in α_a SOTE	Estimated α_a Mean	Estimated α_a Range	Mean Air Flux Rate (scfm/sq ft)
Madison, WI	Ceramic grid	Step feed	17.8	12.6-26.2	14.8	Rising from inlet to outlet	0.64	0.42-0.98	0.28
Madison, WI	Ceramic & SAN plastic tubes	Step feed	11.0	7.5-13.4	15.0	Rising from inlet to outlet	0.62	0.46-0.85	0.53
Madison, WI	Wide-band, fixed-orifice coarse bubble diffusers	Step feed	10.0	7.9-10.9	15.0	Random	1.07	0.83-1.19	0.53
Whittier Narrows, CA	Ceramic grid	Plug flow	11.2	9.3-15.2	13.5	Rising from inlet to outlet	0.45	0.35-0.60	0.21
Whittier Narrows, CA	Jet aerators	Plug flow	9.4	7.8-10.8	13.5	Rising from inlet to outlet	0.58	0.48-0.72	0.37
Brandon, WI	Jet aerators	Complete mix	10.9	9.7-12.1	12.5	Random	0.45	0.40-0.50	0.13
Brandon, WI	Jet aerators	Complete mix	7.5	7.4-7.7	12.5	Random	0.47	0.46-0.48	0.39
Orlando, FL	Wide-band, fixed-orifice coarse bubble diffusers	Complete mix	7.6	6.8-8.4	13.0	Random	0.75	0.67-0.83	0.92
Seymour, WI	Ceramic grid	Plug flow	16.5	12.0-18.8	13.8	Random	0.66	0.49-0.75	0.07
Lakewood, OH	Ceramic grid	Plug flow	14.5	12.4-15.9	13.3	Rising from inlet to outlet	~~[illegible]~~ 0.53	0.44-0.57	0.14
Lakewood, OH	Ceramic grid	Plug flow	8.9	7.0-11.1	13.3	Rising from inlet to outlet	0.31	0.26-0.37	0.09
Brewery	Ceramic grid	Complete mix	14.2	12.5-15.2	19.2	Uniform	0.37	0.32-0.37	0.30
Brewery	Static aerators	Complete mix	7.4	5.7-8.8	19.8	Uniform	0.50	0.36-0.51	0.53

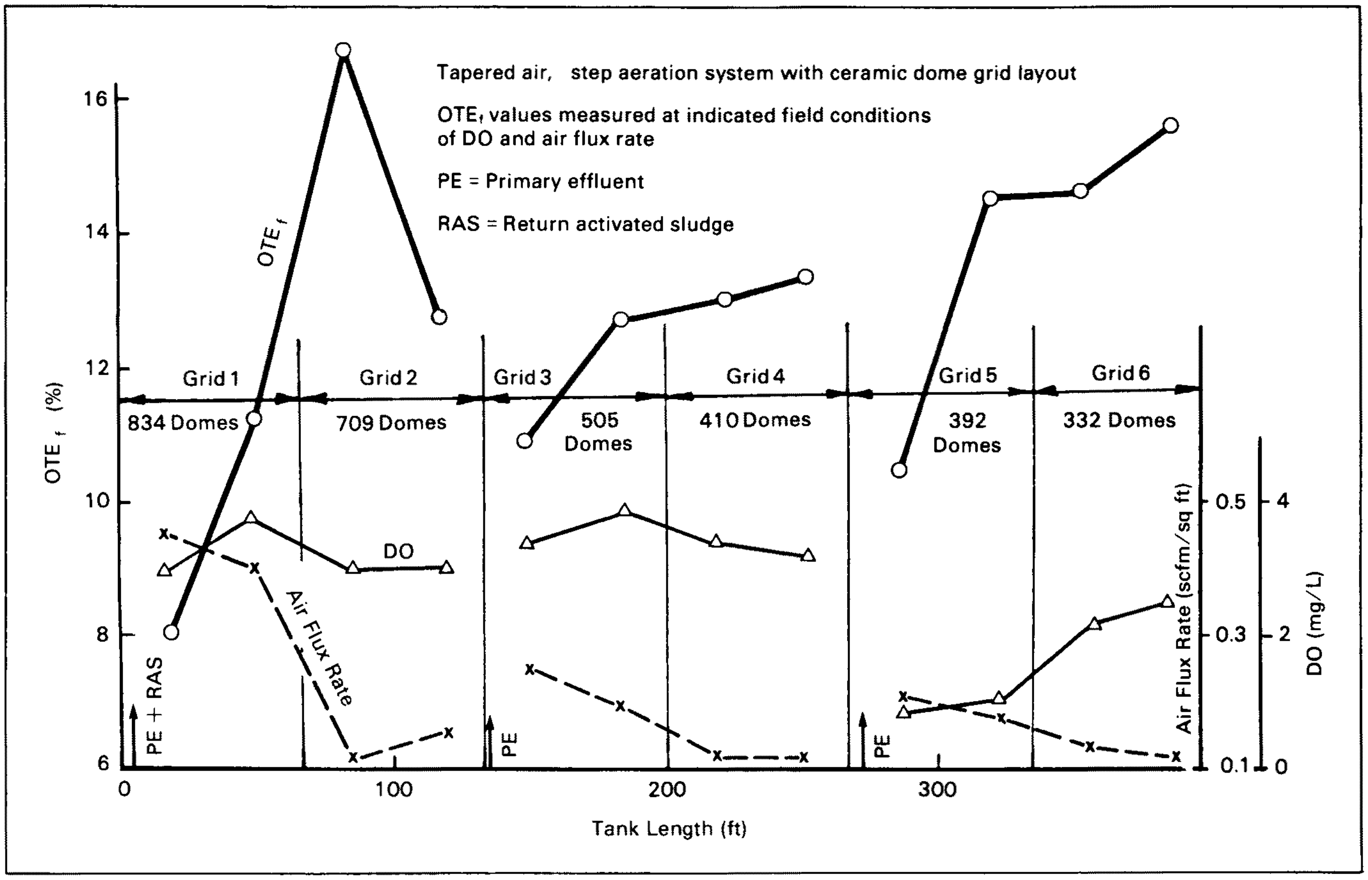


Figure 10.

Gas Transfer Analysis Along Tank Length, Madison, WI[47]

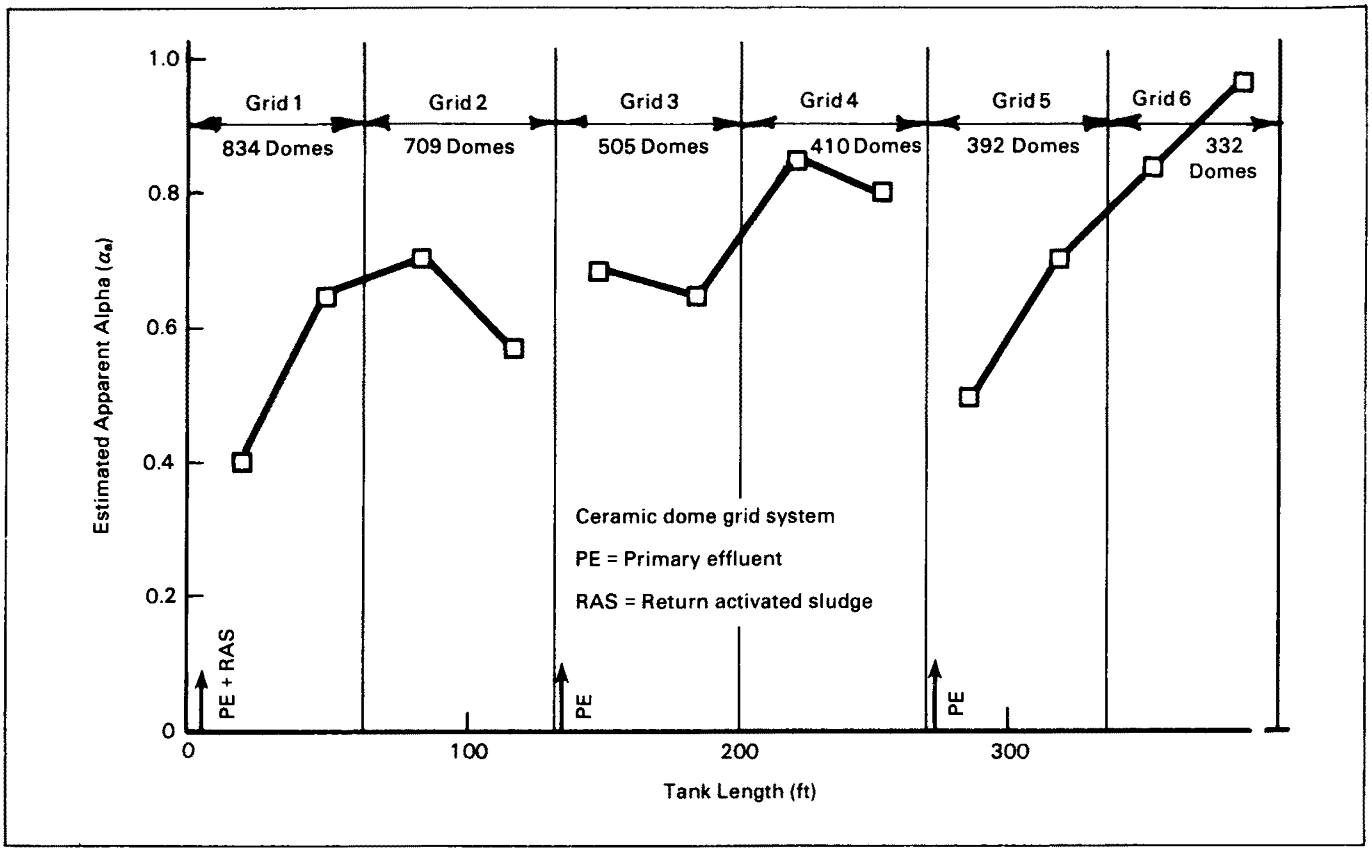


Figure 11.

Estimated Change in Apparent Alpha with Tank Length, Madison, WI[47]

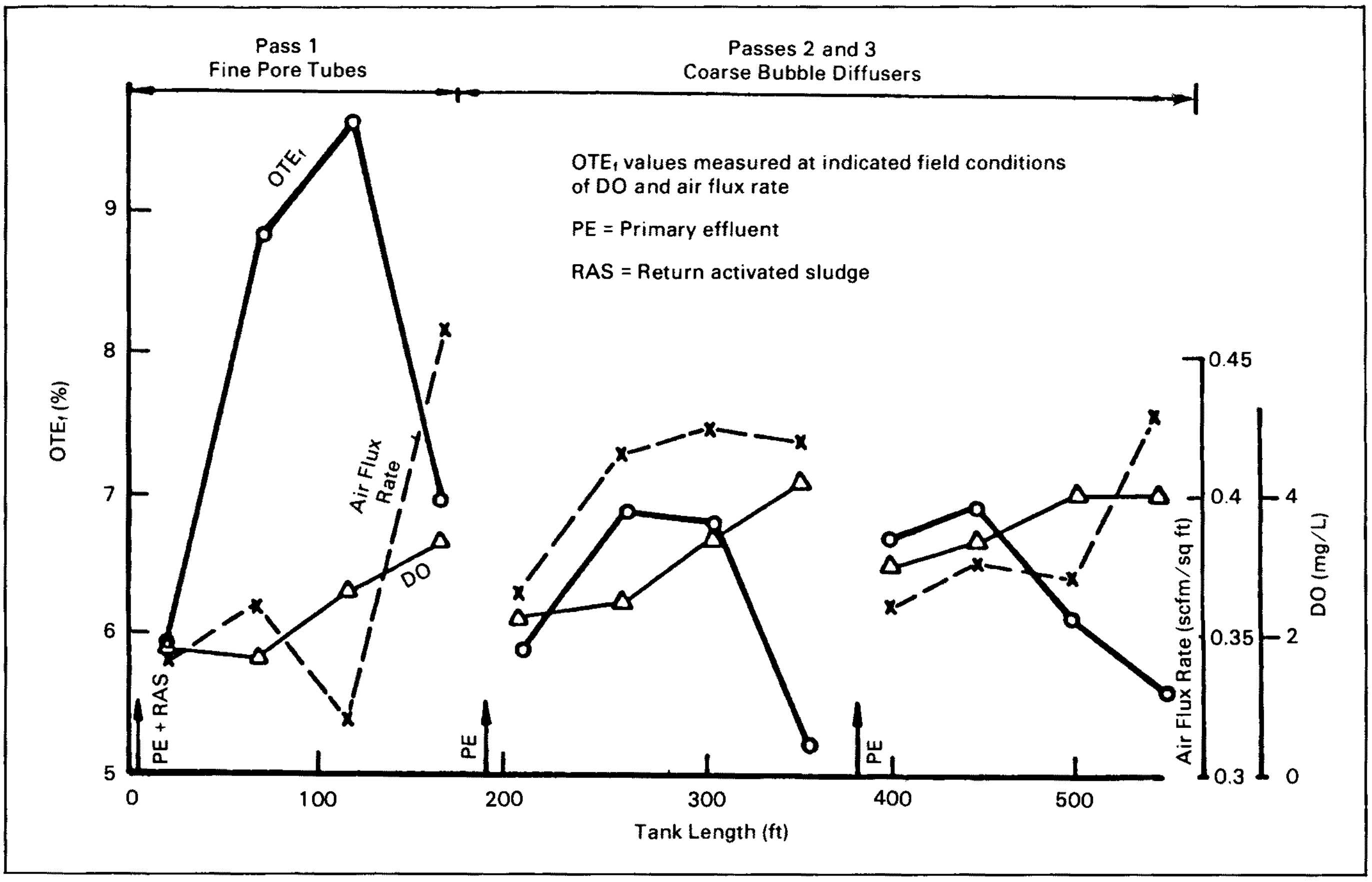


Figure 12.

Gas Transfer Analysis Along Tank Length, Madison, WI[47]

Table 8.

Process Water Oxygen Transfer Comparison for Selected Tubular Diffusers at Madison[47]

Diffuser Type	Location*	OTE_f (%)	DO (mg/L)	α_aSOTE (%)
Wide-Band, Fixed-Orifice Coarse Bubble Diffusers	Station 8	8.0	0.9	8.3
New Flexible Sheath Tubes	Station 9	11.6	1.7	14.2
Used SAN Plastic Tubes	Station 9	9.2	1.7	11.3
Wide-Band, Fixed-Orifice Coarse Bubble Diffusers	Station 10	8.0	2.0	10.3
New Ceramic Tubes	Station 11	12.9	1.7	16.0
Used Ceramic Tubes	Station 11	9.1	1.7	11.0
Wide-Band, Fixed-Orifice Coarse Bubble Diffusers	Station 12	7.0	1.2	8.3

*Refer to Figure 14.

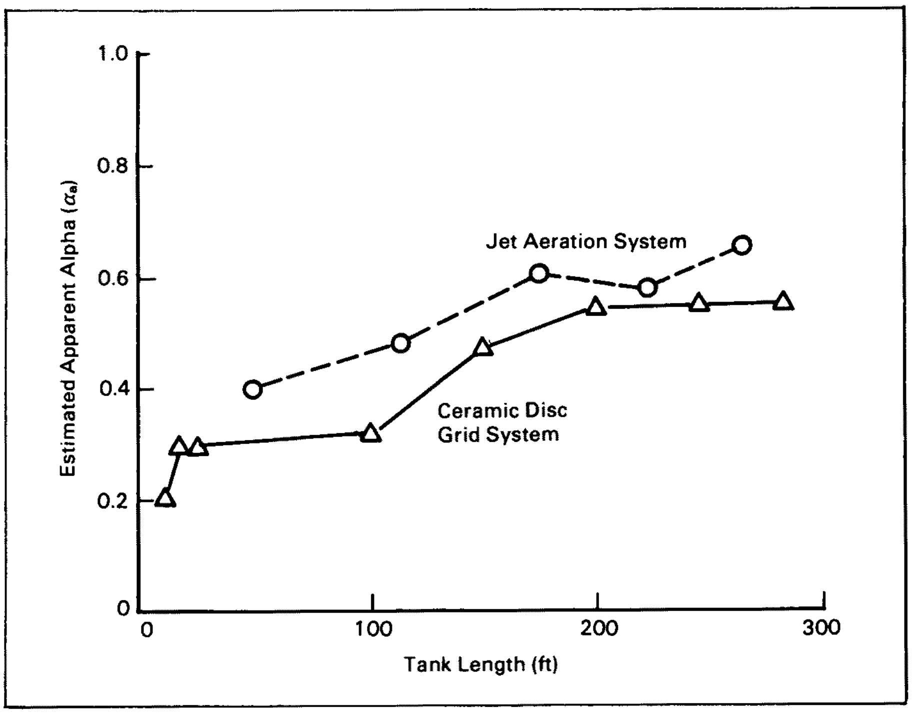


Figure 13.

Estimated Change in Apparent Alpha with Tank Length, Whittier Narrows, CA[50]

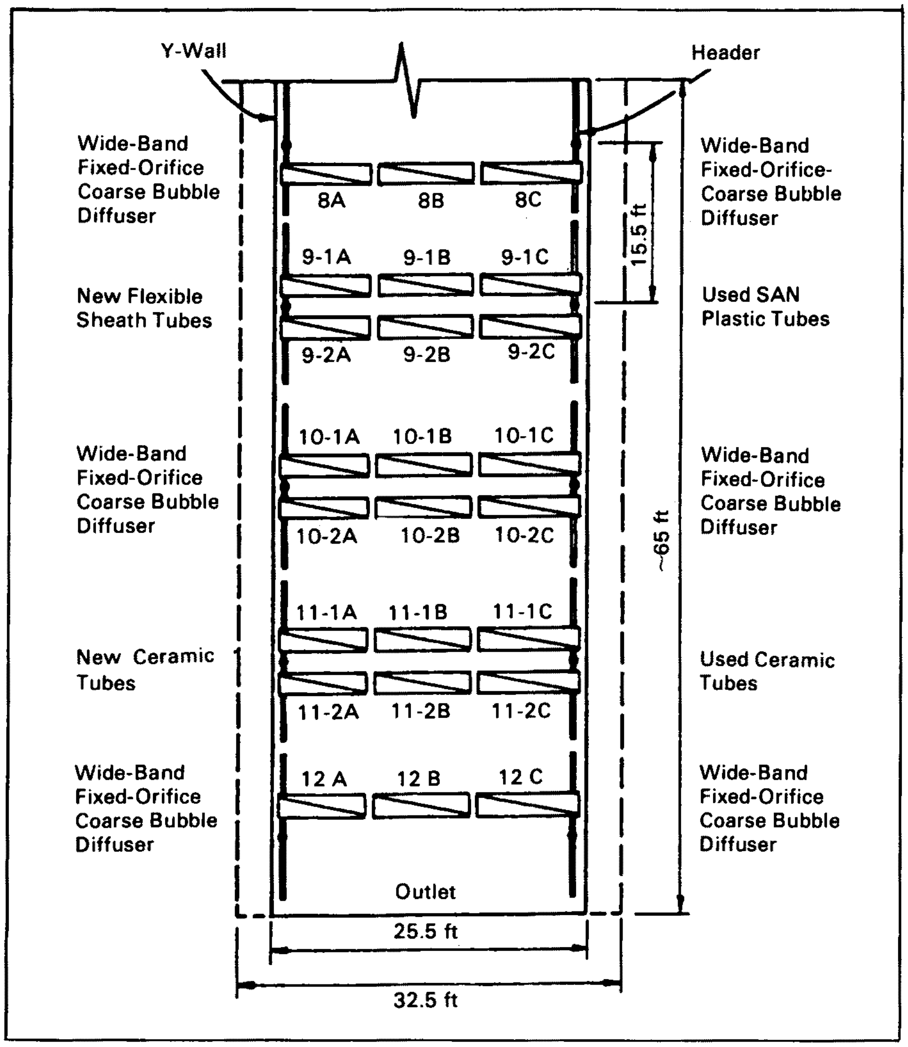


Figure 14.

Diffuser and Off-Gas Hood Sample Site Layout for Comparative OTE_f Analysis of Table 8[4]

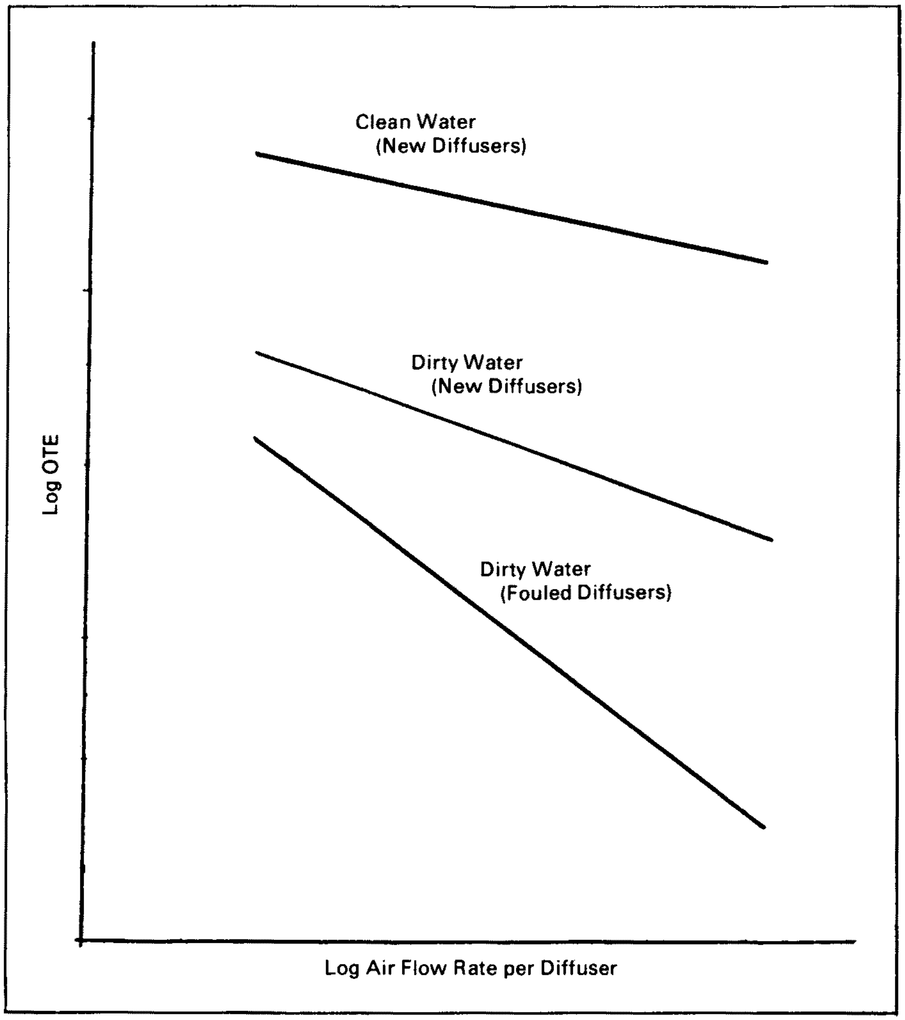


Figure 15.

Change in OTE with Fine Pore Diffuser Fouling—A Hypothetical Case

Operation and Maintenance Considerations

Preceding sections of this report have described the various fine pore diffused aeration systems available and discussed their performance characteristics. Considerations relative to the operation and maintenance (O&M) of fine pore diffusers are addressed in this section. Design and installation practices are examined specifically as they relate to O&M and operating problems commonly encountered. Techniques are reviewed for dealing with these problems, the most frequently occurring of which is diffuser fouling. The causes of, and approaches to coping with, diffuser fouling are given special emphasis in this discussion.

Impact of System Design and Installation on O&M

The principal objective in the design of fine pore aeration systems should be to provide a system with the lowest possible life cycle cost, maintaining an optimum balance between capital and long-term O&M expenditures. Since long-term O&M characteristics will generally be determined by the capabilities and constraints originally designed into such systems, it is important that due consideration be given during design to anticipated O&M requirements. In some cases, relatively minor capital expenses can lead to significant reductions in overall cost by reducing those requirements.

This subsection assesses the impacts of process design, materials selection, aeration basin design, air supply design, and aeration system installation on O&M. Emphasis is placed on identifying key areas where additional consideration during design can lead to significant long-term benefits.

Process Design

The operating characteristics of fine pore diffusers are different than those of other oxygen transfer devices, and these differences affect process design. While diffused aeration systems can produce strong vertical mixing components, horizontal components will generally either be unidirectional (as where the diffusers are located along only one wall of the basin as in a spiral roll configuration) or largely nonexistent (as in full floor coverage applications). Consequently, the wastewater flow pattern is likely to approach plug flow in character above certain length-to-width (aspect) ratios, establishing a gradient in process oxygen demand (high to low) from the aeration basin inlet to the outlet.

Wastewater constituents may also affect fine pore diffuser OTEs to a greater extent than they do other oxygen transfer devices, resulting in lower alpha factors. Diffuser layout design is strongly affected by this phenomenon since the region in the aeration basin where oxygen demand is likely to be the highest (at the tank inlet) is also the region where the alpha value is likely to be the lowest. This combination of practical considerations usually requires that fine pore diffuser density be substantially increased in the inlet portion of a plug flow basin to avoid DO deficiencies and potential process upsets during high-load operation.

For most fine pore diffusers, the practical maximum-to-minimum operating range in air flow rates per diffuser is roughly 5 to 1, providing an approximate 4 to 1 range in oxygen transfer capacity. The lower air flow limit per diffuser, which is set by the manufacturer, is the gas rate required to maintain a uniform flow of air across the surface of the diffuser. Operation below this limit for an extended period of time has been found to result in accelerated diffuser fouling rates.[17] The upper limit corresponds to the air flow rate beyond which headloss across the diffuser control orifice increases substantially and/or OTE decreases significantly.

Taken together, the above factors generally dictate that fine pore diffused aeration systems be designed with tapered aeration capabilities in tanks with high aspect ratios. At a minimum, the diffuser density, i.e., the effective basin floor area per diffusion unit, should vary with the highest density near the tank inlet and the lowest at the tank outlet. The design should be capable of meeting expected variations in air flow requirements, considering both variations in process oxygen requirements and alpha factors along the length of the aeration basin. It may also be desirable to section the diffusion system into grids, with independent air supply control to each grid. For example, a total of three grids might typically be provided in an aeration basin with a length-to-width ratio of 3 to 1 or greater.

Failure to provide proper aerator tapering in tanks with high aspect ratios or in staged tanks can result in inadequate oxygen transfer capacity and low DO concentrations at the inlet end. Such conditions have been found to accelerate biofouling of fine pore diffusers (discussed in more detail below) and contribute to other process-related and/or operational problems.[53] On the other hand, overdesign, particularly insufficient tapering of diffuser density in the middle and latter stages of a long plug flow tank, can lead to inefficient use of energy when the air flow rate to meet the minimum operating requirement per diffuser exceeds that to meet process oxygen requirements.

In some cases, it may not be possible to accurately forecast future variations in oxygen demands and alpha values along an aeration basin. If the aeration system is designed with sufficient oxygen transfer capacity and turndown capability, however, process operation can be adjusted to meet actual demands. For example, assuming that adequate flexibility has been designed into the air supply system, overaeration caused by the maintenance of minimum air flow rates per diffuser can be combatted by removing diffusers from the area of the aeration basin that is overaerated.

Aeration Basin Design

The mixing characteristics of a particular oxygen transfer system may necessitate the use of inlet and outlet flow distribution schemes to prevent short-circuiting in the aeration tank. Weirs, baffles, multiple gates, or favorable mixing patterns induced by diffuser placement may be used for this purpose. Consideration should also be given to the point of entry of flow into an empty aeration basin. For example, entry over a weir may be acceptable when the basin is full but may cause damage to the diffusers and/or header system below when the basin is empty. In this case, an alternate means of filling the basin must be provided (perhaps through the basin drainage system).

As previously discussed, many fine pore aeration systems are nonretrievable while in service; this necessitates that the aeration basin be drained to gain access to the diffusers. Because of the fouling characteristics of these diffusers (discussed below), periodic access via basin drainage will be required. A reliable and easy-to-operate aeration basin drainage system capable of completely draining the basin in a convenient time interval (say 8 to 24 hours) is recommended. The required frequency of drainage will vary depending on the rate of fouling and the cleaning methods used. Adequate volumes of nonprocess water should also be provided, including hydrants or faucets at frequent intervals along the aeration basin, to assist in basin washdown.

Air Supply System Design

The air supply system must be designed to meet both the process oxygen needs and the operational requirements of the selected fine pore diffusion system. Air requirements will vary as process oxygen requirements vary, and the air supply system must have sufficient flexibility to meet these demands if the full energy benefits of the fine pore diffusion are to be realized. Achieving this flexibility will generally require the use of multiple blowers, each provided with appropriate turndown capability, i.e., variable-speed motors on positive displacement blowers or various means of control on centrifugal blowers. The air flow meter(s) and flow control valve(s) must also be sized properly for the range of air flow rates anticipated. Flexibility can be enhanced with instrumentation and automated controls that should be integrated with the air supply system design. These control features will be discussed in the upcoming WPCF MOP No. 5.

The small air passage orifices in fine pore diffusers that cause them to be more efficient in transferring oxygen also make them more prone to plugging by particulate matter in the air supply. Proper air filtration must be provided to prevent atmospheric dirt or blower oil from entering the air distribution system and causing air-side plugging of the diffusers. Removing these potentially harmful particles requires efficient air filtration. Manufacturers of ceramic fine pore diffusers have historically recommended a minimum removal of 95 percent of all particles 0.3 micron and larger to avoid air-side plugging of the diffusers. Alternatively, specifications on filtered air quality require particulate concentrations less than 0.1 mg/28 m^3 (1,000 cu ft).[5,7]

Air filters can be located on the inlet to the blowers or in-line in the air distribution system. One drawback of in-line filters is the incremental increase in blower discharge pressure required to overcome losses in the filter. This consumes some power, but the effects can be minimized by properly sizing and maintaining the filters. Large plants may wish to investigate baghouse filters or electrostatic precipitators as economic alternatives to in-line filters. Unique problems such as the filtering of wet air will require special attention.

Uniform distribution of air among individual diffusers in an aeration grid is also an important consideration. The use of fixed-size orifices on individual diffusers is a common practice today to achieve uniform air distribution.

A final consideration is the reliability of the power supply. Interruptions in service allow mixed liquor to enter the air header system through the diffusers and any leaks in the system. Some suspended solids will be filtered out by the diffusers, but some will also enter the system piping. When air supply is resumed, a properly designed purge system should be used to clear the system so that the suspended solids will not be trapped and retained on the inner surfaces of the diffusers. Suspended solids filtered out by the diffusers during a power outage may be retained within the media on resumption of air delivery. These retained solids will result in higher headlosses across the diffusers and may lead to a change in OTE. Consequently, extra care should be taken during design to provide a reliable power supply with appropriate backup to minimize the occurrence of power outages.

Materials Selection and Specification

O&M of fine pore diffused air systems is facilitated when the materials of construction of the diffusion system components are properly selected and specified. These tasks are typically the responsibility of the engineer. Unless the aeration system is provided with the necessary degree of mechanical and structural integrity, the potential energy economies of fine pore diffuser operation will not be realized due to air leaks. Leaks may also allow entry of mixed liquor into the diffusion piping, resulting in plugging of the diffusers from the air side. The detailed aspects of selecting materials for fine pore diffusion vary among manufacturers and with diffuser type. Additional details will have to be considered as new equipment is developed. Nevertheless, some general principles are relevant.

Special precautions must be taken to select materials that will contribute to trouble-free operations of fine pore aeration systems. Factors such as freeze/thaw and sunlight exposure are important. Due consideration should be given to the use of stainless steel appurtenances.[53] Specifying stainless steel for items such as anchorage straps and bolts will add little to overall system cost, but may significantly increase the mechanical and structural integrity of the system. The selection of corrosion-resistant materials is also recommended since corrosion products can be transported to diffusers through the air supply system, producing air-side diffuser plugging.

Many fine pore diffusion systems use plastic header piping to reduce system capital cost. Although such use has proven successful, the resulting system is more fragile than the steel or cast iron piping systems previously used.

All normal and abnormal forces should be considered during the design of the header piping anchorage system. This can be especially critical if a new fine pore aeration system is to be used in conjunction with another aeration system in the same basin. For example, expansion and contraction of the header system must be taken into account during both header layout and detailed design. The anticipated temperature range should consider both in-service and out-of-service conditions, e.g., a drained tank on a hot summer day. Long-term structural/mechanical integrity and long-term maintainability will be greatly affected by the consideration given during design to the static and dynamic forces that the air distribution system is expected to withstand.

System Installation

Special precautions are required with regard to certain aspects of fine pore aeration system installation. As an example, all construction debris and dust should be removed from the air supply system before the diffusers are installed. If not removed, these materials can be transported to the diffuser during operation, resulting in plugging. Flushing can be accomplished with either air or water and should be followed by inspection.

Care also must be exercised in the installation of the more fragile components of the air header and diffusion system. For example, structural failures resulting from overtightening of the retaining bolt have occurred with one type of ceramic dome diffuser. Overtightening during installation resulted in failure of either the plastic retaining bolt or the plastic saddle that it was inserted into.[53] The problem may be addressed by the use of a properly-set torque wrench to install the bolt. This example illustrates the need for increased concern with some fine pore systems, particularly those using plastic components. These considerations are more crucial to a fine pore than to a coarse bubble aeration system because air leaks can lead to proportionally higher air flow and energy requirements, thus negating the major advantage of the fine pore system.

Impact of Fouling Phenomena on O&M

Background

Porous ceramic plate diffusers, introduced in the United States in the 1920s, had become the predominant air diffusion device by mid-century.[5,7] Various types of foulants were identified by early investigators, and the list has been expanded by recent studies to include the following:[26]

Air Side

- Dust and dirt from unfiltered air
- Oil from compressors or viscous air filters
- Rust and scale from air pipe corrosion
- Construction debris due to poor cleanup
- Wastewater solids entering through diffusers or pipe leaks

Liquor Side

- Fibrous material attached to sharp edges
- Inorganic fines entering media at low or zero air pressure
- Organic solids entering media at low or zero air pressure
- Oils or greases in wastewater
- Precipitated deposits, including iron and carbonates
- Biological growths on diffuser media

A number of different cleaning procedures have been developed, identified, and applied including the following:[5,7]

Ex-Situ

- Refiring
- Silicate-phosphate washing
- Alkaline washing
- Acid washing
- Detergent washing

In Situ

- Acid washing
- Flaming
- High pressure water hosing
- Withholding influent (creating endogenous conditions)
- Sandblasting
- Chlorine washing
- Air bumping (air turned off and on)
- Steam cleaning
- Gasoline washing
- Drying

The rate of fouling has historically been gauged by the rise of back pressure while in service. Since significant biological fouling can take place with little attendant rise in backpressure, this provided a crude and qualitative measure at best.

It was common practice in earlier times to operate a number of diffusers from a common plenum. This practice resulted in less uniformity of air distribution than is obtained today with the use of restrictive flow control orifices on individual diffusers. The lack of air flow uniformity probably augmented the rate of biological fouling experienced in the past.

In the 1960s and early 1970s, the relative cost of energy to maintenance labor was low. As a consequence, many of the ceramic plate installations were replaced with less efficient, fixed-orifice coarse bubble diffusers. In the middle 1970s, this trend was reversed and many of those installations are now being replaced by porous media diffusers with individual air flow control.

In the early 1980s, better methods of measuring the degree of fouling and the effects of cleaning became available. These methods include dynamic wet pressure (DWP), bubble release vacuum (BRV), the ratio of one to the other, and chemical, as well as microbiological, analysis. The practice of employing pilot diffusers that could be removed from the tank and individually analyzed also came into use.[26]

Concurrently, better methods were being developed to measure the performance of operating aeration systems, which permitted better appraisal of the effects of fouling and facilitated better preventive and/or corrective maintenance scheduling. These methods include inert gas tracers, off-gas analysis, a dual nonsteady state technique that uses hydrogen peroxide, and DO and respiration rate profiles.[46,47,64-66] Off-gas equipment has been effectively used to evaluate the adverse effects of fouling on both full-scale systems and on individual diffusers.[47]

Fouling Processes

Recent work has contributed measurably toward an increased understanding of some of the mechanisms of fouling.[67] For example, it has become apparent that flux rate is a parameter that can have a significant influence on the rate of fouling and its consequences. Flux rate may be expressed in several ways. For the purposes of this discussion, apparent flux rate is defined as the air flow rate per diffuser or diffusers divided by the effective diffuser area involved. Local flux rate is defined as the air flow rate per unit area of a small defined segment of a given diffuser. Effective flux rate is defined as the weighted average flux rate for one or more diffusers. This value may be obtained for a given diffuser by measuring the local flux rates on representative sample positions of a diffuser and dividing the sum of the products of flux rate and air flow rate of the individual sample points by the sum of the measured air flow rates.

Types of fouling may be differentiated on the basis of the effects of flux rate on them. For one classification of foulants, fouling rates are increased by high local flux rates and reduced by low local flux rates. Included in this classification are air-side fouling from air-borne particulates and liquid-side fouling by precipitates such as metal hydroxides and carbonates. In the process of fouling, the areas of the diffusers with the highest local flux rate foul more rapidly, which serves to reduce the flux rate in high flow areas and to increase it in low flow areas, the combined effect of which is to improve uniformity of air distribution. The effective flux rate approaches the apparent flux rate as fouling progresses. In the case of chemical precipitate fouling, the accumulation of foulants in the pores reduces the effective pore diameter and the backpressure or DWP rises correspondingly. Due to the reduced effective pore diameters and the smaller bubbles produced, OTE does not decline and can actually increase. At the same time, the increase in DWP can exceed the capabilities of the air supply system and process air delivery may fall short of requirements. An idealized representation of OTE and backpressure (DWP) changes with time under fouling conditions of this type is shown in Figure 16a.

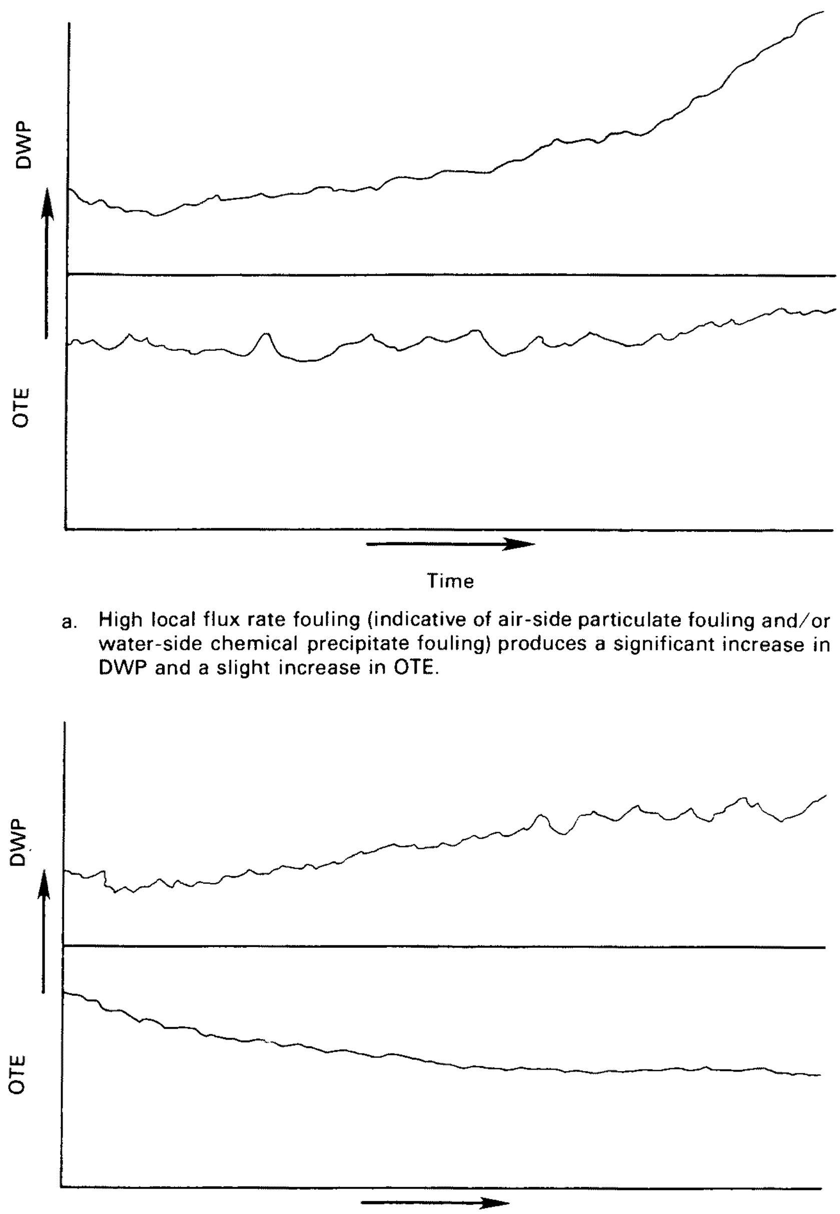
Another classification of foulants causes fouling rates to increase with low local flux rates and decrease with high local flux rates. Included in this category are microbiological slimes. Examples of this type of fouling may be observed on the underside of fine pore tubular diffusers and on the less pervious portions of planar diffusers.

As fouling progresses with the latter type of foulant, low local flux rates tend to further decrease, high local flux rates tend to increase, and air distribution becomes progressively less uniform. A condition can be reached where the flux rates in the small remaining working areas of the diffusers are so high that subsequent fouling is nearly completely arrested. The net result of high effective flux rates for individual diffusers or groups of diffusers is a substantial reduction in OTE. Figure 16b is an idealized representation of OTE and backpressure (DWP) changes with time under fouling conditions of this type.

Process variables that appear to affect the rate of biofouling are not fully understood. Experience and test data[67] provide some indications that the rate of biofouling is increased by operation at high organic loading rates and/or low air flow rates. Other data indicate that biofouling rates may be accelerated by the presence of certain types of industrial wastes, particularly high-strength, readily-biodegradable, and/or nutrient deficient wastes.[68] It is believed that under service conditions all of the types of fouling discussed above, and some others in addition, can occur singly or in combination with variable dominance from plant to plant and within the same plant from time to time.

Fouling Observations

Substantial data are available and in the process of being assembled regarding fine pore diffuser fouling and its effects. Unfortunately, consistent methods of reporting have not as yet been developed. Table 9 is a tabulation of fouling rate data from a number of ceramic diffuser-equipped municipal treatment plants that are considered to be representative of the data base from which it was selected. A similar selection of fouling rate data is presented in Table 10 from various treatment plants using ceramic diffusers in which a significant fraction of the wastewater is of industrial origin. A parameter called BRV (bubble release vacuum) is introduced in Tables 9 and 10. BRV is defined as the negative pressure required to form and release bubbles in tap water at a given location or locations on a given diffuser at an air flux rate of 5.1 $L/m^2/s$ (1 scfm/sq ft).[62] Fouling rates in terms of ΔBRV/yr and ΔDWP/yr were calculated from actual measurements of pressure difference assuming a linear increase with time. Since fouling rates usually are not



a. High local flux rate fouling (indicative of air-side particulate fouling and/or water-side chemical precipitate fouling) produces a significant increase in DWP and a slight increase in OTE.

b. Low local flux rate fouling (indicative of water-side biological fouling) produces a slight increase in DWP and a significant decrease in OTE.

Figure 16.

Effect of two types of fine pore diffuser fouling on DWP and OTE

constant with time, these values are not directly comparable, but are believed to be useful in generating approximate estimates.

Foulants in plants A, M, N, HI, JI, and KI were known to contain higher-than-usual fractions of inorganic constituents. Diffusers in these plants also exhibited higher ΔDWP/ΔBRV ratios with the exception of plant KI where the inorganic constituents appeared to be very loosely attached to the diffusers.

A number of tentative observations may be proposed from Tables 9 and 10 as well as other ongoing work:

- Fouling rates appear to be widely variable for a given plant as well as at a given location within a tank.
- Industrial plant fouling rates appear to be higher than those of municipal plants.
- Air-side fouling due to particulates in the air has not been found to be a significant adverse factor in any of the installations cited in Table 9 or10 or in the data base of the approximate 50 plants from which they were drawn.
- The visual appearance of foulants has failed to consistently provide reliable bases for identifying the nature or origin of the foulants.
- In plug flow regimes, the fouling rate is greatest at the influent end of the tank. If the influent end air flux rate is reduced below the level required to maintain positive DO, fouling can progress down the tank.
- Predominately biological and/or inorganic fouling may reduce OTEs up to one-half of their original values in a matter of weeks.[74] Yet, in other situations, very little reduction in OTE may be noted in over a year.
- Pilot plant fouling tests appear to correlate reasonably well with full-scale tests that employ the same diffusers at comparable air flow rates.[74]
- Ferrous sulfate (and probably other metallic salts) added ahead of or to the aeration tank for phosphorous control may aggravate fine pore diffuser fouling.[74]
- Silica has frequently been found as a major constituent of fine pore diffuser foulants.

The present data base is not sufficient to develop firm conclusions on the above observations. A current, pressing need exists to analyze and expand the data base being assembled for fine pore diffuser systems with respect to their tendencies to foul and the consequences thereof. Insufficient information is available to evaluate the fouling tendencies of flexible sheath diffusers. Relative fouling rates for glass-bonded ceramic diffusers and porous plastic diffusers are not known. The comparative overall fouling rates of plug flow and complete mix systems also are not well documented. Various biological, physical, and chemical factors

Table 9.

Representative Ceramic Diffuser Fouling Data for Municipal Treatment Plants

Plant	Diffuser Type	Exposure Time (Days)	BRV (in. W.G.) Initial	BRV (in. W.G.) After Exposure	DWP (in. W.G.) Initial	DWP (in. W.G.) After Exposure	ΔBRV (in./yr)	ΔDWP (in./yr)	ΔDWP / ΔBRV	Reference
A	Discs	120	--	9.0	6.6	8.6	9.1	6.1	0.67	69
	Discs	120	5.9	11.6	6.5	8.4	17.3	5.8	0.33	
	Discs	133	5.6	8.5	(5.8)	(7.0)	8.2	3.3	0.40	
	Discs	360	5.7	10.7	5.3	9.6	7.6	3.8	0.51	
	Discs	90	6.3	27.4	6.0	9.3	20.0	17.4	0.87	
B	Discs	365	5.8	16.3	6.5	8.7	10.5	2.2	0.21	69
C	Discs	365	6.0	23.0	6.2	11.2	17.0	4.0	0.29	69
D	Domes	1100	5.7	36.8	5.5	16.8	10.3	3.8	0.36	70
E	Discs	210	6.2	18.0	5.8	10.5	20.6	8.2	0.40	69
G	Discs	93	--	--	6.0	14.3	--	32.6	--	69
	Discs	93	--	--	5.8	10.8	--	19.6	--	
H	Discs	100	4.9	11.8	(5.0)	9.8	25.1	17.5	0.70	69
K	Domes	210	(5.0)	13.0	5.0	9.2	19.9	7.3	0.53	69
	Domes	210	(5.0)	11.2	5.0	11.4	10.8	11.1	1.01	
L	Domes	360	5.0	9.8	5.0	7.3	4.8	2.3	0.48	69
	Domes	360	4.0	11.7	5.0	6.8	6.7	1.8	0.27	
M	Domes	350	4.3	10.3	4.0	6.5	6.0	2.5	0.42	69
	Domes	350	4.3	17.5	4.0	9.1	13.5	5.1	0.38	
N	Discs	900	(5.6)	68.9	(5.6)	18.6	25.5	13.0	0.51	71
	Discs	900	(5.6)	199	(5.6)	130	77.8	50.3	0.65	

Numerical values in parentheses represent estimated values.

influencing the rate of fouling need further investigation and quantification. Finally, standardized O&M procedures need to be developed to address fouling for different types of fine pore diffusers.

Process Monitoring

Fouling phenomena can induce changes in process performance. Proper process monitoring is necessary to define system performance, identify process problems, and determine system O&M requirements. Recommended process monitoring measurements are listed in Table 11.

Air-side and liquid-side fouling of the type produced by high local air flux rates causes an increase in diffuser headloss at constant air flow rates. Such increases in wet headloss may be detected by operating conditions within the air supply system. Depending on the specific design approach, an increase in air supply system pressure (monitored, for example, in the blower discharge header or by increased opening of the flow control valves) can indicate an increase in diffuser headloss. Significant increases in blower pressure may be indicative of extensive fouling of major portions of the diffuser system. For this reason, blower pressure along with air flow rate should be monitored on a daily basis.

While overall system pressure monitoring serves as a potential indicator of extreme fouling, it does not provide a very sensitive indication of increased diffuser headloss, nor will it necessarily reveal significant fouling of the type inversely affected by air flux rate. For example, a 10-percent increase in system air pressure (an apparently minor increase) may represent a much higher percentage increase in diffuser headloss. Even more importantly, this buildup in headloss may be having a significant detrimental effect on OTE. In addition, fouling of only a portion of the diffusion system may lead to a substantial redistribution in air flow but little increase in overall system pressure. Consequently, use of a monitoring technique more sensitive than system pressure is desirable and often necessary.

Increased headloss sensitivity is provided by measuring DWP with a device of the type illustrated in Figure 17. Individual diffusers are outfitted with an array of manometers that allow measurement of the headloss across the air distribution control orifice and across the diffuser. Headloss across the orifice is used in determining the rate of air flow through the diffuser, while headloss across the diffuser media indicates the degree to which the diffuser has fouled. By outfitting selected individual diffusers throughout the aeration system with DWP measuring setups, the condition of various portions of the diffusion system can be monitored.

Table 10.

Representative Ceramic Diffuser Fouling Rates for Industrial Treatment Plants

Plant	Diffuser Type	Plant Type	Exposure Time (Days)	BRV (in. W.G.) Initial	BRV (in. W.G.) After Exposure	DWP (in. W.G.) Initial	DWP (in. W.G.) After Exposure	ΔBRV (in./yr)	ΔDWP (in./yr)	ΔDWP / ΔBRV	Reference
AI	Domes	Pulp & Paper and Domestic	720	5.7	28.5	5.5	50	141	22.6	0.16	69
BI	Discs	Pulp & Paper and Domestic	120	9.5	29.1	8.9	15.0	59.3	18.6	0.31	72
CI	Discs	Pulp & Paper	16	5.8	48.0	6.2	12.0	962	132	0.14	69
	Discs	Pulp & Paper	92	5.6	(92)	5.7	20.0	341	56.5	0.17	
DI	Discs	Pulp & Paper	218	6.3	27.4	6.0	9.3	35.3	5.3	0.16	69
EI	Discs	Domestic & Industrial	21	5.8	28.4	5.3	12.7	383	128	0.33	69
GI	Discs	Pharamaceutical	34	5.8	(31.9)	6.~~2~~3	~~12.0~~ 13.3	~~962~~ 280	~~132~~ 75.2	~~0.14~~ 0.27	69
	Discs	Pharamaceutical	31	5.8	12.0	5.8	7.8	73.0	24.1	0.33	
HI	Discs	Food Processing	420	5.6	50.6	5.6	42.4	39.1	32.0	0.82	69
	Discs	Food Processing	420	5.6	61.0	5.6	43.0	53.0	37.4	0.71	
JI	Discs	Brewery	90	6.2	54.0	5.1	45.9	219	186	0.85	69
	Discs	Brewery	90	5.9	66.8	5.2	48.0	270	194	0.72	
KI	Plates	Domestic & Industrial	30	6.0	129	--	--	1470	--	--	73
	Plates	Domestic & Industrial	77	6.8	50.0	7.5	12.4	208	17.2	0.10	
	Plates	Domestic & Industrial	58	7.0	12.1	--	--	33.0	--	--	
LI	Domes	Domestic & Industrial	110	6.5	31.6	6.0	12.5	83.4	18.3	0.22	69

Numerical values in parentheses represent estimated values.

Table 11.

Recommended Process Monitoring Measurements for O&M of Fine Pore Diffusers

- System Pressure
- Dynamic Wet Pressure
- Bubble Release Vacuum
- Specific Air Flow (Air Volume per Unit of Oxygen Demand Satisfied)
- OTE Measurement
- Air Distribution Assessment
- Visual Observations
  - Boils
  - Coarse bubbling
  - Poor air distribution

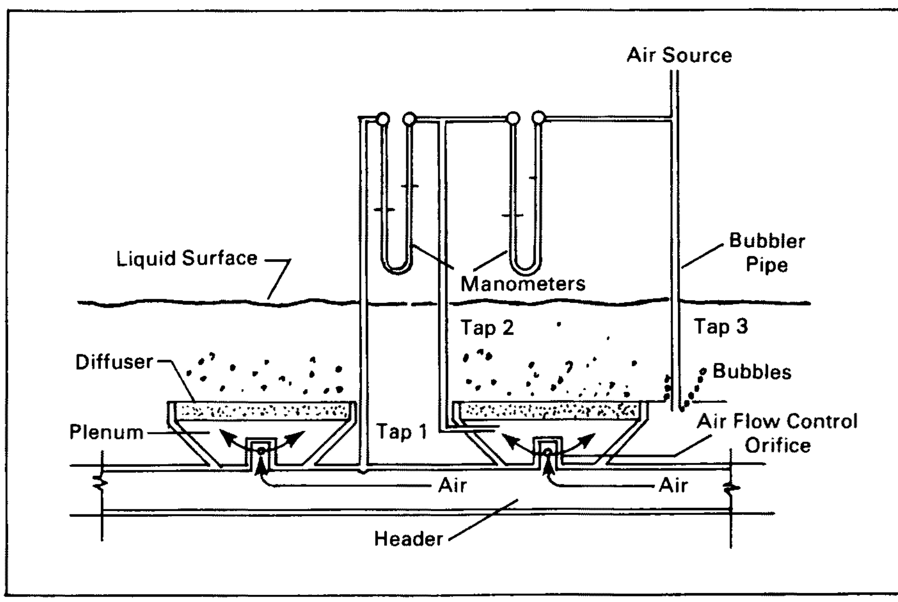


Figure 17.

On-Line Device for Monitoring DWP of Fine Pore Diffusers

Since diffuser fouling can substantially decrease OTE without significant attendant increases in backpressure, effective process monitoring should include other parameters in addition to diffuser headloss and system pressure measurements. Savings in power obtainable by optimizing diffuser cleaning schedules will usually justify the modest equipment and labor costs required for such additional monitoring. Candidate parameters for additional monitoring include OTE and BRV. Another candidate parameter is specific air flow, which is the volume of air supplied per unit of oxygen demand satisfied. Air flow rate is measured in standard m^3 (standard cu ft), while the reduction in oxygen demand can be measured in terms of BOD or COD removed plus ammonia nitrogen oxidized to nitrate nitrogen. The ratio m^3 air supplied/kg O_2 demand satisfied (cu ft/lb) should be routinely monitored along with aeration basin DO. An increase in the specific air flow, a decrease in mixed liquor DO, or both may indicate a decrease in OTE, although other conditions such as an increase in system organic loading can produce similar effects. OTE can be measured using a variety of techniques described in the previous section. The easiest and most direct is the off-gas method.

These quantitative measures of oxygen transfer performance should also be combined with visual observations of the system. The surface pattern on the aeration basin should be smooth with no air "boils." Boils arise because of breaks in the air supply piping that allow large quantities of air to leak from the distribution system at one or more point sources. Such leaks should be repaired as quickly as possible, both because of the decrease in OTE that will occur due to maldistribution of air along with the release of coarse bubbles and because of the possibility of further damage to the diffusion system.
Nonuniformity of the surface pattern can signify that portions of the diffusion system are becoming plugged. For example, an unusually low degree of surface turbulence in a segment of the aeration basin may indicate restriction of air flow to that portion of the basin resulting from fouled diffusers. Cleaning of the affected diffusers may be required.

The size of the air bubbles evident on the aeration basin surface can also provide an indication of fouling. Loosely adherent biomass on fine pore diffuser media causes the formation of large bubbles. Some degree of "coarse bubbling" is typically observed at the inlet end of an aeration basin that may not be a result of biofouling. It is believed that the observed phenomenon may sometimes be due to high local air flux rates caused by surfactants contained in the influent wastewater. These surfactant materials are quickly adsorbed and/or degraded by the activated sludge, which restricts the size of the "coarse bubble" zone. On the other hand, if biofouling occurs, the coarse bubble zone can expand until, in the worst cases, it covers the entire surface of the aeration basin. It is recommended that the surface of the aeration basin be inspected and photographed when initially placed in service to become familiar with the size and appearance of the bubbles at the inlet and outlet ends of the basin. This familiarity will provide a basis for recognizing more extreme coarse bubbling should it occur later.

Once problems are identified qualitatively by visual observation, quantitative measurements should be made to confirm the type and extent of fouling and the type of cleaning required. Experience indicates that qualitative observations can be a valuable tool when used in conjunction with quantitative measures of system oxygen transfer performance.

Preventive Maintenance

A major finding of a survey conducted by Houck and Boon[17] on dome diffuser plants in the United Kingdom and Holland was that the historically excellent O&M performance of these grid systems was due to both the knowledge and diligent care of treatment plant operators. Routine draining, tank and grid washdown, and hardware inspection were standard operating procedures at all plants surveyed. Operators were also aware of the symptoms of problems in the diffuser system and were quick to respond.

Preventive maintenance is necessary to keep a fine pore aeration system in proper working order and at an optimum level of performance and to minimize the rate of diffuser fouling. It should also eliminate the need for emergency maintenance resulting from system failure.

Preventive maintenance on the air filtration and supply system can virtually eliminate air-side dust and particulate fouling of fine pore diffusers. The guidance provided by the equipment manufacturer is generally sufficient for this purpose. Proper maintenance procedures will also decrease the frequency of interruptions in air supply that can lead to the entry of solids into the distribution system as discussed previously. The deposition of solids on the liquid side of the diffusers and subsequent penetration into the upper pores will also decrease with a decrease in air supply interruptions. Operation at or above minimum allowable air flow rates per diffuser will assist in preventing the deposition of solids on diffuser media.[17]

Experience indicates that the above preventive maintenance steps will help reduce the rate of liquid-side fouling of fine pore diffusers. Fouling will still occur (although at a lower rate), however, and the diffusers will have to be cleaned periodically.

Diffuser Cleaning

A variety of fine pore diffuser cleaning techniques are currently available. They can be broadly classified as process interruptive or process noninterruptive. Process interruptive cleaning techniques require that the aeration basin be taken out of service to provide access to the diffusers, while process noninterruptive techniques do not require such access. A further distinction in cleaning techniques can be made between those that do not require removal of the diffusers from the basin (*in-situ*) and those that do require diffuser removal (ex-situ). All ex-situ techniques are process interruptive, while only some *in-situ* techniques are process interruptive.

Among the important *in-situ* cleaning methods in use today are water hosing, steam cleaning, and acid cleaning, all of which are process interruptive, and gas cleaning, which is process noninterruptive. Hosing with either high pressure or low pressure sprays and/or steam cleaning will effectively dislodge loosely adherent, liquid-side biological growths. The application of 14-percent HCl (a 50-percent solution of 18° Baume inhibited muriatic acid) with a portable spray applicator to each ceramic diffuser following hosing or steam cleaning and, then, rehosing the spent acid is effective in removing both organic and inorganic foulants.[67,74,75]

Gas cleaning consists of the injection of an aggressive gas (HCl or formic acid) into the air feed to the fouled diffusers. The cleaning agent is transported to the diffuser by the air flow where it may dislodge most foulants. The exceptions are atmospheric dust deposited on the air side of the diffuser, which has not been found to be a significant source of fouling as previously reported, and granular material such as silica deposited on, or incorporated in, a gelatinous slime adherring to the liquid side of the diffuser.

Refiring is the most expensive cleaning technique used and applies only to ceramic diffuser elements. It involves removal of the diffuser from the aeration basin, placing it in a kiln, and heating it in the same fashion originally used in its manufacture. The result is removal of most foulants from, or incorporated in, the diffuser element and restoration of the element to essentially its original condition.

The quantitative effectiveness of the various cleaning methods being used today for the variety of foulants encountered on different fine pore media is not well documented. Furthermore, costs for these methods are not generally available. Current research being conducted by EPA/ASCE[76] is attempting to develop a sound data base on cleaning technology. As a general premise at this point in time, it is believed that most fine pore diffusers (including virtually all those cited in Tables 9 and 10) can be restored to substantially original conditions by one or combinations of the following *in-situ* cleaning methods: water hosing, steam cleaning, gas cleaning, and acid soaking.[69,72,73,77]

The EPA/ASCE research program[*] [76] may ultimately identify the factors affecting diffuser cleaning rates and costs and provide an adequate data base from which to develop typical cleaning procedures and schedules for various generic devices. Until that occurs, the effects of various cleaning methods and their required frequencies should be considered site specific and should be developed specifically for each system.

Several methods are available to measure the effects of diffuser cleaning on the characteristics of the diffuser. One approach is to apply the process monitoring procedures previously discussed. The effects are measured as a decrease in system pressure or diffuser DWP, an increase in system OTE, or a decrease in system specific air flow, i.e., air flow per unit of oxygen demand satisfied. Techniques can also be applied to directly measure the characteristics of individual diffusers. These include OTE[47] chemical analysis of foulants, and measurements of air flow capacity of individual diffusers. These latter techniques include specific permeability and BRV, which measure, respectively, the air flow rate at a specified applied diffuser headloss and the applied headloss required to induce air flow through the diffuser.[25,67] Pilot-scale cleaning tests have also been shown to produce correlative data applicable to full-scale cleaning situations.[77]

As discussed above, the effectiveness and costs of the various fine pore diffuser cleaning techniques is an area of active research. The development of detailed information in this area should be forthcoming. However, there is little doubt that the incorporation of an effective diffuser cleaning schedule is a necessary and justifiable component of any fine pore diffused aeration preventive maintenance program.

Cost Tradeoff Analysis

Diffuser cleaning may be accomplished according to a regular preventive maintenance schedule that balances the cost of diffuser cleaning against the power cost savings resulting from higher system OTE and lower system pressure. It may be possible to generate a relationship of the type illustrated in Figure 18. System power costs decrease with higher OTE due to lower system air requirements. On the other hand, the cleaning costs required to maintain a certain average OTE increase as the target OTE increases. This occurs because an increased cleaning frequency and, perhaps, a more rigorous cleaning method may be required to maintain a higher OTE. The optimum OTE is the OTE that minimizes the sum of the power cost and the cleaning cost required to maintain that OTE, thus producing the lowest overall system operating cost. This same concept may be applied to system pressure.

It should be recognized that Figure 18 is an idealized plot. It presumes, among other things, that the fouling rate and its effects remain constant with time and that the relationship of cleaning vs. OTE does not progressively change. A cost-effective solution to overcoming these assumptions could consist of instituting routine monitoring programs and initiating diffuser cleaning at set-point changes in OTE or DWP, whichever occurs first.

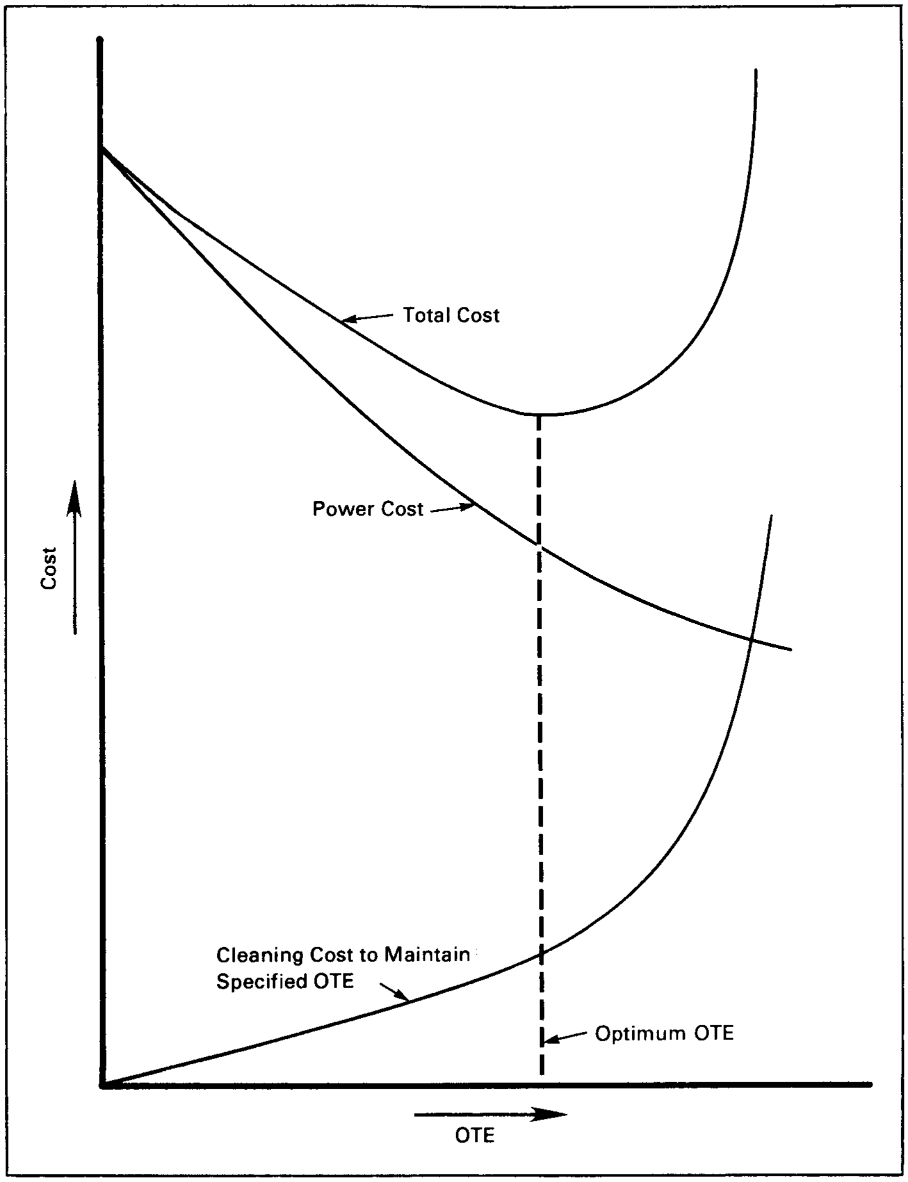


Figure 18.

Idealized Plot of Optimum OTE to Balance Power and Diffuser Cleaning Costs

Retrofit Considerations

The aeration equipment used in activated sludge service performs the dual roles of supplying oxygen to the process and maintaining the mixed liquor solids in suspension. Retrofit evaluations should be considered whenever more efficient, reliable aeration devices become commercially available. The principal benefit of retrofitting an existing aeration system with fine pore diffusers is to reduce the air flow required to provide the oxygen necessary for effective activated sludge treatment. This reduction in required air flow can result in significant energy savings if proper design and O&M attention are given to all system components. Estimates of electrical energy cost increases of 25 to 35 percent in excess of inflation by the year 1989 have been made[78].

Other reasons for considering fine pore retrofitting are to:

- replace existing aeration equipment that has reached the end of its useful life,
- increase treatment capacity to handle higher influent flow and/or organic load, and
- improve process removals to meet more stringent National Pollutant Discharge Elimination System (NPDES) Permit limits.

Increased oxygen transfer capability in itself may not alter plant treatment capacity. Adequate capacity must also exist in all unit processes and appurtenances to handle higher plant loadings. If air supply capacity is the limiting factor, however, replacing existing coarse bubble aeration systems with fine pore diffusers can increase plant treatment capacity.

System Design Factors

The design of a fine pore diffused aeration system to replace an existing coarse bubble diffused aeration system or a mechanically aerated system is essentially the same as any aeration system design with some notable exceptions:

- The aeration tank dimensions are fixed as the tanks are already in existence.
- The air supply and air distribution systems are already in place in the case of an existing diffused air system.
- The design and actual flows and organic loadings to the aeration system are known through review of the design criteria for the existing system and recent plant records.

These "given" conditions must be reviewed and evaluated during the design phase of the retrofit project as outlined in the discussions that follow.

Wastewater Characteristics

The wastewater characteristics that impact the design of a fine pore aeration system are flow, BOD_5 load to the aeration system, and NH_3-N load to the aeration system if the plant's NPDES Permit requires nitrification all or part of the year. These parameters establish the oxygen demand placed on the system. Other constituents present in the influent may significantly affect oxygen transfer rates and/or promote the rapid plugging or fouling of fine pore diffusers. For example, very hard water, or other sources of calcium from industrial wastes, may contribute to the precipitation of inorganic compounds within the media of fine pore diffusers. In addition, surfactants, or surface active agents, are typically detrimental to oxygen transfer rates in mixed liquor.

The capabilities of the new aeration equipment should be assessed for satisfying current operating requirements and future design conditions of flow and load. Present and anticipated future NPDES Permit effluent limitations establish the mass of oxygen demanding substances that may be discharged with the plant effluent.

Methods for determining actual oxygenation requirements (AOR) are well documented in the literature.[79,80]

Existing Facilities

Aeration Tanks:

Aeration tank dimensions and configurations have a number of important impacts on proper diffuser selection. Minimum air flows required to maintain adequate mixing in the basins are dictated by tank geometry. Minimum mixing requirements with coarse bubble diffusers in a cross roll pattern are generally estimated at 0.7 to 1.2 $m^3/hr/m^3$ (12 to 20 scfm/1000 cu ft) of tank volume.[81] Mixing requirements with fine pore tube diffusers in the same arrangement are comparable. Minimum air flow rates for mixing with fine pore diffusers in a grid configuration are estimated in the range of 1.8 to 2.7 $m^3/hr/m^2$ (0.1 to 0.15 scfm/sq ft) of tank surface area.~~[80]~~[79]

The number of aeration tanks and the interconnecting piping design strongly influences the type of process modifications that are possible with a given activated sludge system. The flexibility to dewater single tanks or portions of individual tanks must be carefully considered in selecting fine pore diffusion devices and methods for cleaning them when they become fouled. Finally, aeration tank depth and geometry have a direct impact on OTE for both the existing aeration equipment and the proposed fine pore retrofit system as described in the section on Performance Characteristics.

Air Supply and Distribution:

If the aeration system to be replaced is either a diffused air system or mechanical aerators with sparged air, air blowers and distribution piping will already be present. Obviously, a plant with mechanical surface aerators will require installation of new blowers and air piping to use fine pore diffusers. Replacement blowers may be required in some cases due to age or lack of flexibility or capacity.

The energy savings available with fine pore diffusers result from a reduction in the volume of air required to provide the process with necessary oxygen. On the other hand, savings may be partially offset by the increased operating pressure in fine pore diffusion systems. The reduction in air flow, if achieved, will result in operating fewer blowers and/or operating the same blowers at different points on their performance curves.

Most air supply blowers in municipal treatment plants are either single- or multi-stage centrifugal types or rotary positive displacement units. The efficiency of both single- and multi-stage centrifugal blowers can vary from more than 80 percent to less than 40 percent, depending on the blower itself and the operating combination of discharge volume and discharge pressure. Estimating input horsepower for these units should always be done using actual performance curves generated from power factor and power consumption measurements at the plant.

Potential power savings from operating at reduced air flows with fine pore diffusers can be completely negated by a decrease in blower operating efficiency resulting from the reduction in air flow itself. It is critical, therefore, to accurately estimate blower horsepower for the actual conditions that will prevail with the retrofitted system and not by using compression formulae that require an estimate of blower efficiency to determine power for a given discharge condition.

Centrifugal blower capacity should be regulated to the extent possible by throttling on the inlet side, as significant power savings are available at any duty point. A method for estimating blower brake horsepower for a centrifugal blower with inlet throttling is illustrated in Figure 19. Rotary positive displacement blower capacity cannot be varied by throttling for all practical purposes. Air flow to the aeration system can be changed only by operating more or less units, varying speed, or by "blowing off" some of the air to atmosphere. Wasting air to the atmosphere may reduce the actual air flow to the aeration system, but will not reduce the power consumption of the blowers. Here again, it is crucial that blower horsepower be estimated using actual blower performance curves and under the anticipated actual conditions of operation because efficiency for rotary positive blowers is by no means constant from one unit to another.
Blower peak capacity should be checked at the maximum anticipated inlet temperature and the minimum expected pressure at the blower inlet flange. The overall blower system integrity should be evaluated in terms of its turndown capability and flexibility of operation.

The existing air distribution piping can in general be reused with some reservations. Because air flow rates will decrease with enhanced OTE, the size of the existing blower discharge headers and air mains that deliver air to the tanks will normally be sufficient. Depending on the type and arrangement of fine pore diffusion equipment, the individual drop pipes into the tanks may also be large enough. The air distribution system should be checked for capacity, corrosion, and integrity.

For new systems that will employ full floor coverage grid configurations and fewer air drops per aeration tank, each drop pipe should be sized such that air velocities at average flow rates are less than 900 m (3,000 ft/min) to avoid excessive air pressure drop in these reaches of pipe.[7]

Air Filtration:

Blower inlet filters will effectively remove contaminants from the outside air but will not protect the diffusers from dirt, rust, scale, or other debris that might already be in the downstream piping. It is recommended, therefore, that careful consideration be given to the use of in-line filters. In some cases, it may even be desirable to locate filters adjacent to the air drops into the aeration system so that new corrosion-resistant pipe need only be located between the filters and the diffusers. Existing piping systems composed of galvanized or stainless steel will present little danger of present or future rust or scale particles plugging the diffusers if blower inlet filters are selected. Existing painted or uncoated steel or iron pipe, however, should be reused only with extreme caution unless in-line filters are installed downstream.

Diffuser Selection

Selection of the proper fine pore diffuser for a given retrofit situation will depend on the oxygen transfer capabilities of the device within the constraints of the existing aeration tank geometry, existing blower characteristics, wastewater properties, desired O&M requirements, and the desired air flow control scheme. Refer to the discussions in previous sections of this report.

Economic Analysis

General

The factors used in the design of a fine pore diffusion retrofit system also comprise the basis for determining its economic viability. Installation of fine pore equipment

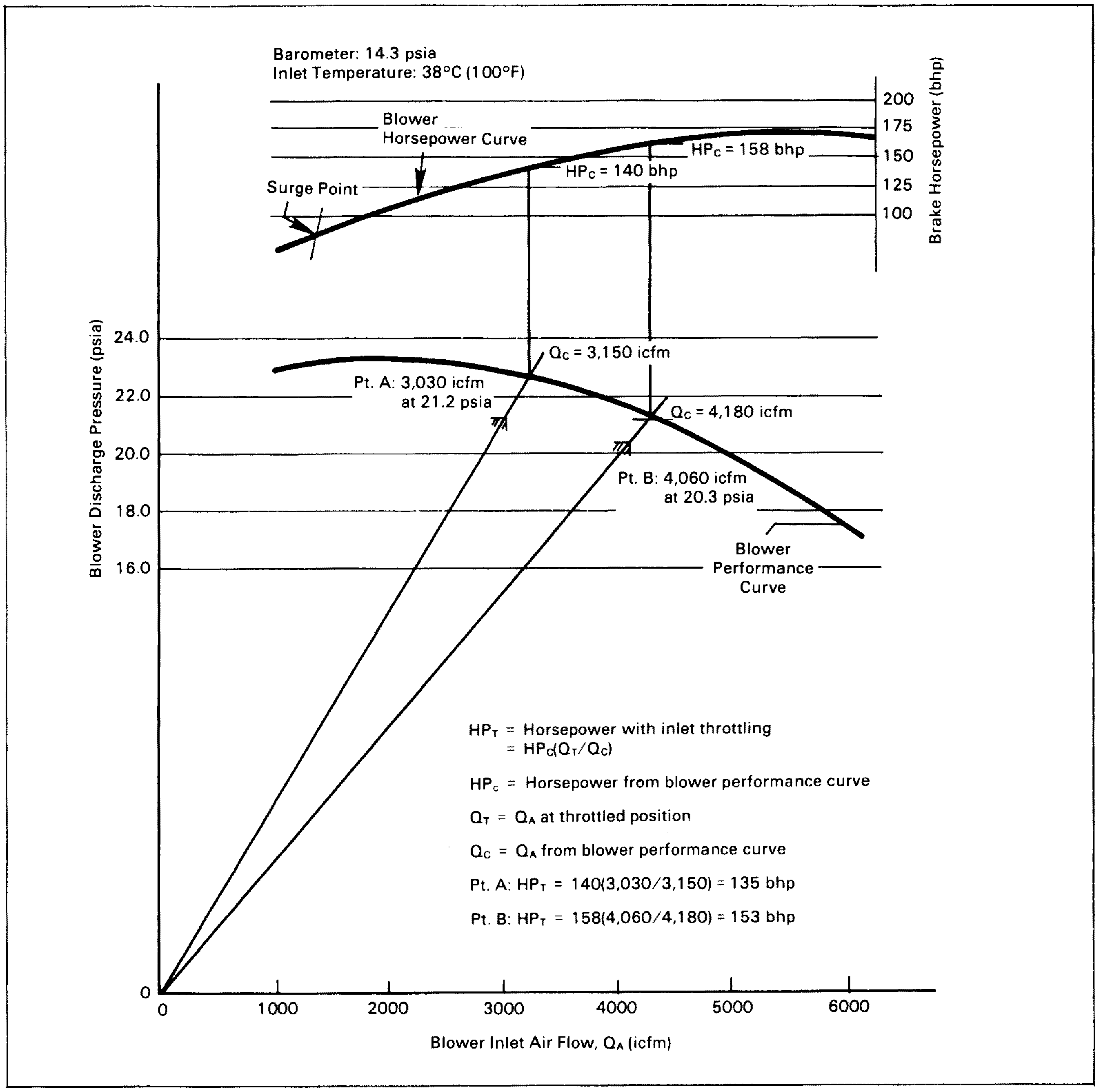


Figure 19.

Method for Estimating Centrifugal Blower BHP with Inlet Throttling (Power Computation per Reference 82) should be undertaken only if a reasonable return on investment can be foreseen. The cost effectiveness of retrofitting is most appropriately based on present day flow and loading to the plant rather than anticipated future increases and should consider the total present worth of the investment as well as simple payback.

Determining System Cost

The cost of a fine pore retrofit includes the new aeration equipment, modifications to the existing air filtration system, air distribution piping modifications if required, and replacement or modification of the air supply equipment as necessary. If the existing system uses mechanical aerators, a completely new air supply and distribution system will obviously be needed. The cost of installation, either by a private contractor or the owner, must also be included.

Determining Annual Savings

Net annual savings in operating costs with fine pore diffusers consist of annual electrical (or other) energy savings resulting from the reduction in air flow to the aeration tanks, less any additional O&M costs associated with the fine pore diffusers. Annual power cost savings can be determined by comparing the average input power required for operating the existing system and the estimated average input power for operating the new system. Power determinations should be made using actual blower performance curves. Power requirements should also be estimated with varying inlet temperatures depending on the time of year. One method of accounting for the variables involved is to develop average air flow requirements for the existing and proposed aeration equipment on a monthly average basis and compute horsepower input monthly. Minimum air flow requirements for mixing should be determined and compared with estimates of air flow for satisfying oxygen demand alone. This is especially important in plants with NPDES Permits that specify seasonal nitrification. When mixing requires more air than necessary to satisfy oxygen demand, the higher air flow rate should be used to determine input power for the period in question.

Determining Additional O&M Costs

Additional O&M costs with fine pore diffusers include diffuser monitoring and cleaning and air filter maintenance and/or replacement. Liquid-side diffuser cleaning is the subject of other sections of this report, and the method used will depend on the type of fine pore device selected and the particular operating characteristics of the plant in question. The cost of the labor and materials for diffuser cleaning must be accounted for in the economic analysis. In addition, labor and material for monitoring diffuser conditions and air filter maintenance and/or replacement must also be factored into the economic analysis.

Determining Economic Viability

Economic viability of a fine pore diffuser retrofit project can be evaluated by comparing the present worth of all future energy savings minus the O&M costs of the fine pore diffuser system against its initial capital cost. In determining the present worth of both future savings and costs in the following example, a "real" (inflation-free) discount rate will be used. This avoids the need to inflate future prices. An inflation-free discount rate, r, can be obtained from a "market" discount rate, R, by adjusting the latter for the inflation rate, I:

$$r = (R - I)/(1 + I)$$

For a planning period of n years, the net present worth of project savings, NPWS, can be calculated as:

$$NPWS = SPWF(r,n)(EAS) - ICC$$

where:

SPWF(r,n) = series present worth factor at discount rate r over n years

$$SPWF = [(1+r)^n - 1]/[r(1+r)^n]$$

EAS = estimated annual savings

ICC = initial capital cost

For the project to be economically viable, NPWS must be positive over the planning period.

EAS can be written as follows:

$$EAS = AES - AROM - EACC$$

where:

AES = annual energy cost savings

AROM = annual cost of routine O&M on the fine pore diffuser system, e.g., air filter cleaning, air flow monitoring, etc.

EACC = equivalent annual cost of diffuser cleaning

If the diffusers are cleaned every t years at a cost of DCC, the EACC can be expressed as:

$$EACC = (DCC)(r)/[(1+r)^t - 1]$$

In this manner, the effect of alternative diffuser cleaning frequencies can be analyzed.

An equivalent payback period can be defined as the length of the planning period that yields zero net present worth savings. From the expression above for NPWS, this occurs when:

$$SPWF(r,n) = ICC/EAS$$

A table of series present worth factors at discount rate r can then be consulted for the value of n with entry closest to the computed SPWF. This payback period should not be interpreted as one based on actual cash flow since it incorporates the equivalency effects of discounting.

Example Evaluation

A generalized example of a simplified economic evaluation of fine pore diffuser retrofitting is presented below. The energy savings analysis is for one month only. For a complete analysis, it is recommended that appropriate costs be determined for each month in a 12-month period.

Flow	
Present average	5.0 mgd
Future average	7.5 mgd
Primary effluent BOD_5	120 mg/L
Primary effluent NH_3-N	15 mg/L
NPDES Permit Limit	
BOD_5	30 mg/L
NH_3-N	2.0 mg/L
Average Mixed Liquor DO	2.0 mg/l
Average Water Temperature	18°C (64°F)
Blower Inlet Pressure	14.3 psia
Blower Inlet Temperature	38°C (100°F)
Aeration Tanks	
Number	4
Dimensions	120 ft x 35 ft x 14 ft SWD
Average Power Cost (including demand charge)	$0.06/kWh

Existing Aeration System (Coarse Bubble Spargers)	
α_aSOTE	5.0 percent
OTE_f	4.0 percent (off-gas measurement)
$C^*_{\infty 20}$	10.1 mg/L (see Performance Characteristics Section)
AOR	7,500 lb/d
Mass flow of air	804,400 lb/d
Inlet air flow	8,120 icfm
Air for mixing	3,530 icfm (15 icfm/1,000 cu ft)
Proposed Aeration System (Dome/Disc Diffusers, Full Floor Grid)	
OTE_f	10.8 percent
$C^*_{\infty 20}$	10.2 mg/L (see Performance Characteistics Section)
AOR	7,500 lb/d
Mass flow of air	300,000 lb/d
Inlet air flow	3,030 icfm
Air for mixing	2,015 icfm (0.12 icfm/sq ft)

For this month, mixing does not control, so power cost estimates will be made using the air flow rates required for process oxygen transfer. System pressure required for blower operation should be determined by developing a system head curve. However, pressures are estimated for this example as follows:

	Coarse Bubble	Fine Bubble
Submergence	12 ft - 0. in.	13 ft - 3 in.
Diffuser head loss	0 ft - 8 in.	1 ft - 4 in.
System losses (estimated)	1 ft - 3 in.	1 ft - 3 in.
Total system pressure	13 ft - 11 in.	15 ft - 10 in.
	= 6.0 psig (20.3 psia)*	= 6.9 psig (21.2 psia)*

*Local barometric pressure = 14.3 psia.

Estimated Blower Input Horsepower (from Figure 19):

Existing spargers = 306 bhp,
2 blowers at 4060 icfm each

Proposed fine pore = 135 bhp,
1 blower at 3030 icfm

Input power in kW must take into account blower motor efficiency and the blower/motor flexible coupling efficiency. For this example, motor efficiency is assumed at 90 percent, coupling efficiency at 95 percent.

Estimated Power Costs:

Existing = $11,918
Proposed = $ 5,258

Estimated cost savings for month = $6,660

If this month was typical of the entire year, annual energy savings, ~~EAS~~, AES, would be estimated at $79,920. Actual savings, however, will vary from month to month depending on plant operating conditions.

For this example, no change in blowers is recommended. Development of detailed construction costs and annual maintenance costs is beyond the scope of this report. The initial capital cost is estimated to be $150,000, including the new fine pore aeration system, new efficient air filters, installation, engineering, and contingencies. Additional annual routine O&M costs, AROM, including air filter cleaning and replacement are estimated to be $2,620. Diffuser cleaning is assumed to occur every 2 years at a cost, DCC, of $10,000 (2,000 diffusers at $5/diffuser). An inflation-free discount rate, r, of 8 percent is used.

The estimated annual savings, EAS, for this retrofit project are computed as follows:

$$EAS = \$79{,}920 - 2{,}620 - (10{,}000)(0.08)/[(1+0.08)^2-1]$$

$$EAS = \$72{,}492$$

The net present worth savings, NPWS, for various project periods, n, are summarized below:

Year	SPWF (0.08,n)	Net Present Worth Savings $72,492 (SPWF) - $150,000
1	0.926	-82,872
2	1.783	-20,747
3	2.577	36,812
4	3.312	90,094
5	3.993	139,461
10	6.710	336,421
15	8.560	470,531
20	9.818	561,726

As shown by the progressive growth of the project's net present worth, savings, the investment breaks even after slightly longer than 2 years. If the results of a simplified analysis of the type presented above are favorable, a more rigorous analysis considering actual variations in daily air flow requirements, DO and air flow control schemes, and other operating considerations should be undertaken.

Ongoing Studies

Significant progress has been made in the last 5 years to better delineate the design, testing, maintenance, and control requirements of fine pore diffused aeration systems. The discussions in this report clearly indicate, however, that many gaps still exist in our complete understanding of these systems. For example:

- How do the various fine pore aeration systems perform in processwaters, both in absolute terms and relative to each other?
- How can clean water test data best be translated to field conditions?
- What is the behavior of fine pore diffusers with respect to long-term, liquid-side fouling?
- What strategies will cost effectively control and maintain these systems while still yielding acceptably high field OTEs?

Several research projects have been recently completed or are presently underway in the United States, Canada, and the United Kingdom, addressing the above and other questions related to fine pore aeration system design, performance, operation, maintenance, installation, control, and costs. Among the significant government-sponsored projects are those briefly described below.

In addition to the above-listed government-sponsored studies, numerous shop and field tests are being conducted every day by consultants, manufacturers, and owners of wastewater treatment facilities to better characterize fine pore diffuser behavior. This information also will be disseminated into the public sector as it becomes available.

In the preparation of a comprehensive design information manual on fine pore diffused aeration systems, currently scheduled for completion in late 1987 or early 1988, the ASCE Committee on Oxygen Transfer will make every effort to review all pertinent technical data and information in the literature as well as in unpublished reports made available from consulting engineering firms, municipal treatment plant owners and operators, universities, and research organizations.

Country/Performing Organization:	United Kingdom – Water Research Centre
Sponsors:	Department of Energy – United Kingdom; Environmental Canada – Canada; EPA – United States
Topic/Dates:	Full-Scale Optimization of Fine Pore Aeration to Produce Energy Savings – 1982 to 1985
Objectives/Scope:	To modify the design of ceramic dome diffuser systems in existing aeration tanks at a large treatment plant to significantly reduce the energy used in treating waste-water and to increase the throughput capacities of the modified tanks while still meeting specific effluent objectives.
	To make an economic comparison of the modified vs. the existing systems to produce a fully nitrified effluent of high quality 95 percent of the time in one train and a non-nitrified effluent of 30:20 mg/L (SS:BOD) 95 percent of the time in a second train.
	To obtain design information that will enable new and retrofitted plants equipped with ceramic dome diffuser systems to achieve higher OTEs and greater throughput capacities.
Site:	Rye Meads (England) Sewage Treatment Works (121,000 m^3/d = 32 mgd); parallel process trains

Country/Performing Organization:	Canada - Wastewater Technology Centre
Sponsors:	Environment Canada - Canada; EPA - United States
Topic/Dates:	Full-Scale Demonstration of Energy Savings, Operational Benefits, and Instrumentation/Control in Automated Aeration Systems - 1982 to 1987
Objectives/Scope:	To demonstrate energy savings and improved operation with DO set-point maintenance through automated air distribution and effective blower control. To determine and optimize the true cost of maintaining the integrity of on-line instrumentation and control hardware. To conduct cost/benefit analyses with respect to the benefits of implementing automated DO control. This project is currently evaluating coarse bubble diffused aeration systems. It is anticipated that the systems will be retrofitted with fine pore diffusers before the project is completed.
Site:	Tillsonburg (Ontario) Wastewateer Treatment Plant (6,000 m^3/d = 1.6 mgd); parallel process trains

Country/Performing Organization:	United States - Madison (Wisconsin) Metropolitan Sewerage District
Sponsor:	EPA
Topic/Dates:	Investigation of Biological Fouling of Ceramic Fine Pore Diffusers and the Effectiveness of Several Cleaning Strategies - 1982 to 1985
Objectives/Scope:	To evaluate the effects of selected aeration tank control parameters (DO, total and soluble organic load, and gas flow per diffuser) on the biological fouling of glass-bonded, ceramic fine pore diffusers. To evaluate the effects of these parameters on diffuser characteristics and OTE. To evaluate the effectiveness of a number of cleaning methods on fouled ceramic diffusers.
Site:	Madison (Wisconsin) Nine Springs Wastewater Treatment Plant; 3,800- and 5,600-L (1000- and 1500-gal) pilot aeration tanks; selected full-scale aeration trains; laboratory studies of cleaning

Country/Performing Organization:	United States - Los Angeles County Sanitation Districts
Sponsor:	EPA
Topic/Dates:	Comparative Full-Scale Evaluation of Two Types of Fine Pore Diffusion with Jet Aeration - 1980 to 1985
Objectives/Scope:	To compare over a 6-month period the field oxygen transfer and fouling performance of ceramic dome diffusers (grid configuration), porous plastic tube diffusers (dual spiral roll configuration), and directional flow jet aerators. To evaluate the long-term process performance, oxygen transfer performance, and fouling characteristics of the most efficient of the above systems (which was determined to be the dome diffuser system in the 6-month preliminary phase) at varying volumetric organic loads and under two different flow regimes (plug flow and step aeration).
Site;	Whittier Narrows (California) Water Reclamation Plant (58,000 m^3/d = 15 mgd); parallel process trains

Country/Performing Organization:	United States - ASCE
Sponsor:	EPA
Topic/Dates:	Design Information on Fine Pore Diffused Aeration - 1985 to 1988
Objectives/Scope:	To evaluate the existing data base on the performance of fine pore diffused aeration systems in clean and process waters. To carry out field studies at a number of municipal wastewater treatment facilities employing a variety of fine pore aeration systems to fill perceived data gaps in the design and performance of these systems. To evaluate the field effectiveness of available fine pore diffuser cleaning technologies. To conduct economic analyses of the most promising cleaning technologies and delineate factors affecting the selection of best methods of cleaning for site-specific conditions. To prepare an interim guidance report on fine pore diffused aeration systems. To prepare a final comprehensive design information manual on fine pore diffused aeration systems.
Site:	ASCE (New York, New York) administers project under technical direction of the Steering Subcommittee of the Committee on Oxygen Transfer with studies conducted at a number of selected sites throughout the United States and Europe.

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National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703)487-4650

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